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THE JOURNAL

OF THE

INSTITUTE OF METALS

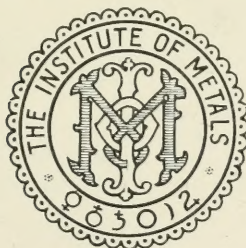
VOLUME IX

EDITED BY

G. SHAW SCOTT, M.Sc.

SECRETARY

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THE INSTITUTE OF METALS

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G. SHAW SCOTT, M.Sc.

Telegraphic Address—"Instomet, Vic. London."

Telephone—Victoria, 2320.

THE INSTITUTE OF METALS,
CAXTON HOUSE, WESTMINSTER, S.W.

June, 1913.

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THE INSTITUTE OF METALS

SECTION I.

MINUTES OF PROCEEDINGS.

ANNUAL GENERAL MEETING.

THE ANNUAL GENERAL MEETING of the Institute of Metals was held at the Institution of Mechanical Engineers, Storey's Gate, Westminster, S.W., on Tuesday and Wednesday, March 11 and 12, 1913, Professor T. Turner, M.Sc., occupying the chair on Tuesday, March 11, prior to the declaration of the result of the ballot for officers for the year 1913. Afterwards, and on Wednesday, March 12, the chair was occupied by Professor A. K. Huntington, Assoc.R.S.M., President.

Mr. G. A. BOEDDICKER (Vice-President), in opening the meeting, said that unfortunately the retiring President, Professor Gowland, was unable to be present at the meeting owing to illness. At that moment he was in the South of France for the benefit of his health, and he was glad to say that the last news received of him was favourable. In his absence a Chairman was required, and he proposed that Professor Turner, their Honorary Treasurer, should temporarily take the Chair.

The resolution was duly seconded, and carried unanimously.

THE LATE SIR WILLIAM WHITE.

Professor T. TURNER, M.Sc., having taken the chair, said that although his duties were, in the main, of a very formal character, it was fitting that a few words should be said at the opening of the meeting in reference to the circumstances

in which the Institute found itself owing to the loss of its first President, the late Sir William White, who passed away so suddenly a few weeks ago. All the members felt a sense of personal loss, because Sir William had occupied the chair on many occasions, and had taken a very keen interest in the inception and the progress of the Institute. As a designer of ships, and as Past-President of those important Institutions, the Civil Engineers, Mechanical Engineers, and Naval Architects, the late Sir William White was known throughout the whole civilized world, while to the members of the Institute he was known as a friend and guide. Only those who served on the Council in the early days were aware how much they were indebted to the experience, the skill, and the tact of Sir William for the smooth, pleasant, and successful way in which the Institute was started; and they now felt they had experienced a loss the depth of which could not be expressed, and which was quite irreparable. All that it was possible to do was to say in a few words how much they sympathized with Lady White and her family in their bereavement, and how much the Institute felt the loss that had been sustained. He moved, therefore, that a letter be sent on behalf of the Institute of Metals in accordance with the words he had just said.

Sir GERARD MUNTZ, Bart. (Past-President), in seconding the motion, said he felt that no words he could utter could adequately express his sentiments in regard to the matter. The late Sir William White was, as Professor Turner had stated, the first President of the Institute. Not only was he its first President, but he was practically its guide in its foundation, and the members were thoroughly conversant with how much he did for the Institute right up to the last. Some of the members were favoured by coming into closer personal contact with the late Sir William than others had been, and he could only say in that regard that he felt the loss of Sir William, not only as a fellow Past-President of the Institute, but as a personal friend and counsellor during his term of office as President. Even if Sir William White had lived, he (Sir Gerard) could not have expressed sufficiently to him his gratitude for the assistance that was

rendered to him when he took up the important office of President, and he could not adequately express that gratitude now. It was very largely to the late Sir William White that, in his opinion, the Institute owed the success to which it had attained.

The resolution was carried in silence, all the members up-standing.

MINUTES.

The SECRETARY (Mr. G. Shaw Scott, M.Sc.) read the Minutes of the General Meeting held in London on September 25 and 26, 1912.

ANNUAL REPORT OF THE COUNCIL.

The SECRETARY read the following Report of the Council upon the work of the Institute during the year 1912:—

IN presenting to the members their Annual Report, the Council of the Institute of Metals have pleasure in stating that the year 1912 marked a period of material development in the activities of the Institute, and a slight growth in the membership.

THE ROLL OF THE INSTITUTE.

The number of Members on the roll of the Institute on December 31, 1912, was as follows:—

Fellow . . . . .	. . . . .	1
Honorary Members . . . . .	. . . . .	4
Ordinary Members . . . . .	. . . . .	578
Student Members . . . . .	. . . . .	23
Total		606

The following table shows the development that has taken place since the foundation of the Institute in 1908:—

	Dec. 31, 1908.	Dec. 31, 1909.	Dec. 31, 1910.	Dec. 31, 1911.	Dec. 31, 1912.
Fellows . . . . .	...	...	1	1	1
Honorary Members . . . . .	...	1	3	3	4
Ordinary Members	350	492	524	555	578
Student Members	5	12	23	27	23
Total	355	505	551	586	606

The Council have conferred on Professor H. Le Chatelier the Honorary Membership of the Institute.

The Council regret to have to record the deaths, during 1912, of the following three members: Mr. J. C. Bull; Engineer Rear-Admiral J. T. Corner, C.B., and Mr. J. Dodd.

The Council are sorry to have to record that, owing to ill-health, the President, Professor W. Gowland, F.R.S., Assoc.R.S.M., has been obliged to relinquish the presidential duties before the completion of his term of office, and desire to express not only their sympathy with Professor Gowland in his illness, but their appreciation of his valuable work for the Institute. In the absence of the President, Professor A. K. Huntington, Assoc.R.S.M., as President-Designate, was appointed Acting-President by the Council.

GENERAL MEETINGS.

During the year 1912 three General Meetings were held. The Annual General Meeting took place in London on January 16 and 17. In the absence of the newly elected President (Professor W. Gowland, F.R.S.), through illness, Professor A. K. Huntington, A.R.S.M., occupied the chair. The Secretary, in the absence of the President, read the latter's Inaugural Address, which was entitled "Copper and its Alloys in Early Times." On January 17 the following Papers were read and discussed:—

1. "Contributions to the History of Corrosion." By ARNOLD PHILIP, B.Sc., A.R.S.M. (Portsmouth).
2. "Further Experiments on the Inversion at 470° C. in Copper-Zinc Alloys." By Professor H. C. H. CARPENTER, M.A., Ph.D. (Manchester).
3. "The Behaviour of Certain Alloys when Heated in Vacuo." By Professor T. TURNER, M.Sc. (Birmingham).
4. "A Study of the Properties of Alloys at High Temperatures." By G. D. BENGOUGH, M.A., D.Sc. (Liverpool).
5. "A Note on the Nomenclature of Alloys." By WALTER ROSENHAIN, B.A., D.Sc. (Teddington).
6. "The Influence of Tin and Lead on the Microstructure of Brass." By F. JOHNSON, M.Sc. (Birmingham).
7. "The Influence of Oxygen on Copper containing Arsenic or Antimony." By R. H. GREAVES, B.Sc. (Cardiff).
8. "A Metallographic Hygroscope." By Professor Dr. CARL A. F. BENEDICKS and RAGNAR ARPI (Stockholm).

The occasion of the next General Meeting of the year was the May Lecture, which was delivered on May 10, 1912, by Sir J. Alfred Ewing, K.C.B., LL.D., F.R.S., on the subject of "The Inner

Structure of Simple Metals," a full report of which will be found in the Journal, vol. viii.

The Autumn Meeting was held in London on September 25 and 26. Admirable arrangements were made by the London Reception Committee, of which Professor W. Gowland, F.R.S., was Chairman, and the meeting was a great success in every way. The following papers were read and discussed:—

1. "The Structural Resolution of the Pure Copper-Zinc β Constituent into $\alpha + \gamma$." By Professor H. C. H. CARPENTER, M.A., Ph.D. (Manchester).
2. "The Effect of Other Metals on the Structure of the β Constituent in Copper Zinc-Alloys." By Professor H. C. H. CARPENTER, M.A., Ph.D. (Manchester).
3. "The Annealing of Coinage Alloys." By T. KIRKE ROSE, D.Sc. (London).
4. "The Effect of Temperatures Higher than Atmospheric on Tensile Tests of Copper and its Alloys, and a Comparison with Wrought Iron and Steel." By Professor A. K. HUNTINGTON, A.R.S.M. (London).
5. "Intercrystalline Cohesion in Metals." (With an Appendix on the formation of Twinned Crystals in Silver.) By WALTER ROSENHAIN, B.A., D.Sc., and DONALD EWEN, M.Sc. (Teddington).
6. "The Solidification of Metals from the Liquid State." By G. T. BEILBY, LL.D., F.R.S.
7. "The Influence of Impurities in 'Tough-Pitch' Copper, with Chief Reference to Antimony." By F. JOHNSON, M.Sc. (Birmingham).
8. "The Influence of Oxygen on the Properties of Metals and Alloys." By E. F. LAW, A.R.S.M. (London).
9. "Oxygen in Brass." By Professor T. TURNER, M.Sc. (Birmingham).
10. "The Joining of Metals." By A. E. TUCKER, F.I.C. (Birmingham).
11. "Autogenous Welding by means of Oxygen and Acetylene of Copper and its Principal Alloys, and of Aluminium." By Professor Dr. F. CARNEVALI (Turin).

In the evening of September 25, a Reception was given at the Royal United Service Institution, Whitehall, by the London Reception Committee.

In the afternoon of September 25, one party of members visited the works of Messrs. Fraser & Chalmers at Erith, whilst another party visited the National Physical Laboratory, Teddington. On the following afternoon one party visited the Brooklands Motor Track and Aviation Ground, another party going to the Royal Arsenal at Woolwich.

The Council desire to record their indebtedness to the Institution of Mechanical Engineers for the courtesy shown in allowing the Annual General Meeting and the May Lecture to be held in their building, and also to the Council of the Institution of Electrical Engineers for

a similar courtesy on the occasion of the Autumn Meeting of the Institute in September.

CORROSION COMMITTEE.

Considerable progress has been made in the investigation of the causes of corrosion of tubes of the four types of alloy selected by the Committee, namely 70 : 30 brass, Admiralty mixture, lead-bearing brass, and Muntz metal. Twelve tubes of each alloy have been tested in the special condenser plant for nine months, *i.e.* from April to December 1912. Three tubes of each composition have been withdrawn for detailed examination; this, however, has not yet been completed. A preliminary examination has shown that a small amount of corrosion, such as that usually met with in tubes that have failed in practice, has occurred in some of these tubes, but has not penetrated to any considerable depth. All the tubes have been found to be covered with a scale of composition similar to that typical of those used in the mercantile marine. Investigation on these tubes is still proceeding.

The plant itself was closed down temporarily on December 31, 1912, pending the supply of further funds for working expenses, which amount to about £100 per annum. It is highly desirable that the experiments with this plant should be continued at the earliest opportunity, and this will be done as soon as the necessary funds are forthcoming.

An extensive scheme of laboratory experiments has been devised with the object of elucidating the nature of reactions which take place during the processes of corrosion and scale formation. It has been found necessary to continue a number of the experiments for periods of several months, as the collection of data is necessarily slow. Hitherto it has not been possible to devise any satisfactory "acceleration" test, so work in this direction has been abandoned for the present.

A considerable number of badly corroded tubes have been sent in for examination by various shipping firms and manufacturers, and afforded useful information. The Investigator is now desirous of obtaining a number of tubes that have endured exceptionally long service in marine or land condensers.

COMMITTEE MEETINGS.

The five Standing Committees, known respectively as the Abstracts Sub-Committee, the Corrosion Committee, the Finance and General Purposes Committee, the Library and Museum Committee, and the Publication Committee, have met regularly during the past year, and

several Occasional Committees have been appointed by the Council for the consideration of special matters.

THE BEILBY RESEARCH PRIZE.

The Special Committee appointed by the Council to discuss with Dr. Beilby the proposed research, as originally suggested in his May Lecture, 1911, has had meetings during the year, and Dr. Beilby was invited to read a Paper elaborating his suggestion at the London Meeting of the Institute in September 1912. This Paper was entitled "The Solidification of Metals from the Liquid State," and was regarded by the Committee as the basis of a research into this subject. The Committee appointed Dr. Cecil H. Desch their Investigator, his remit being as outlined in Dr. Beilby's Paper, and his Report is expected to be made at the next Autumn Meeting of the Institute. Dr. Beilby has kindly placed at the disposal of the Council a sum of £100 to be awarded as an Honorarium in connection with the Research.

NOMENCLATURE COMMITTEE.

As a result of a suggestion contained in Dr. Rosenhain's Paper "A Note on the Nomenclature of Alloys," read at the Annual General Meeting in January 1912, the Council appointed a Nomenclature Committee to consider the re-naming of certain of the non-ferrous alloys.

It was thought desirable by the Council that the Committee should number among its members officially appointed representatives of other Institutions, and this has been arranged, the constitution of the Committee being as follows:—

Institute of Metals.—Dr. W. Rosenhain, B.A. (*Chairman*); G. A. Boeddicker, Esq.; Dr. Cecil H. Desch; Engineer Rear-Admiral G. G. Goodwin, C.B., R.N.; G. Hughes, Esq.; Sir Gerard Muntz, Bart.; A. E. Seaton, Esq.; and Professor T. Turner, M.Sc.

Institution of Electrical Engineers.—W. Murray Morrison, Esq.

Institution of Mechanical Engineers.—George Hughes, Esq.

Institution of Naval Architects.—Sir W. E. Smith, C.B.

Institution of Engineers and Shipbuilders in Scotland.—Alexander Cleghorn, Esq.

North-East Coast Institution of Engineers and Shipbuilders.—The Hon. Sir C. A. Parsons, K.C.B., F.R.S.

Society of Chemical Industry.—Professor W. R. Hodgkinson, Ph.D., M.A.

BIRMINGHAM LOCAL SECTION.

The second session of the Section was very successful, both as regards meetings and finance.

At the close of the session the membership of the Section was as follows:—

Associates	.	.	.	.	.	.	21
Members	.	.	.	.	.	.	51
							<hr/> 72

The membership during the previous session was 45, there being no associates.

During the last session six meetings were held, some excellent papers being read as the following list shows:—

1911.

Oct. 10. Discussion on "The Annealing of Non-Ferrous Metals."

Nov. 14. Paper on "The Gases in Brass Strip Ingots. Notes on the reasons for using dressed moulds, and a description of the apparatus employed in the investigation." By J. CARTLAND, M.Sc.

Dec. 12. Paper on "The Uses of Electricity in Brass and Copper Rolling Mills." By Messrs. MILNS and ANDERSON.

1912.

Feb. 6. Exhibits and Notes on Specimens, illustrating the Influence of Certain Impurities on the Forging Qualities of Copper at a Red Heat; also Notes on the Effect of Zinc on the Micro-structure of White Metal. By L. ARCHBUTT, F.I.C.

Mar. 12. Paper on "The Mechanical Properties of Alloys at High Temperatures." By F. C. A. H. LANTSBERRY, M.Sc.

April 16. Paper on "Cold Rolling Mills." By W. H. A. ROBERTSON.

All the Papers were illustrated by lantern slides.

The average attendance at these meetings was 33; 25 Members and Associates, and 8 visitors.

PUBLICATIONS.

Two volumes of the Journal were published in 1912—Volume VII. being issued in June and Volume VIII. in December. These contained 814 pages of letterpress, plates, and numerous illustrations in the text. The Council are pleased to note that the value of the Journal is being appreciated more and more each year, as the sales of the Journal, both to members and non-members, have been greatly increased during the past year, 179 volumes having been sold during the financial year ending June 30, 1912. The Transactions, or Proceedings, of the following Societies are regularly received in exchange for the Journal of the Institute:—

American Electro-Chemical Society.
 American Institute of Mining Engineers.
 Bureau of Standards, Washington (Department of Commerce and Labour).
 Chemical Industry, Society of.
 Chemical Society.
 Concrete Institute.
 Faraday Society.
 Imperial Institute.
 Institute of Marine Engineers.
 Institution of Automobile Engineers.
 " " Civil Engineers.
 " " Electrical Engineers.
 " " Engineers and Shipbuilders in Scotland.
 " " Mechanical Engineers.
 " " Mining and Metallurgy.
 " " Naval Architects.
 Iron and Steel Institute.
 Junior Institution of Engineers.
 Königliches Materialprüfungsamt, Berlin.
 North-East Coast Institution of Engineers and Shipbuilders.
 Royal Society of Arts.
 Staffordshire Iron and Steel Institute.
 West of Scotland Iron and Steel Institute.

LIBRARY AND MUSEUM.

(a) *Museum.*

During 1911 there was established at the offices of the Institute a Museum of Metals tending to show how non-ferrous metals may fail in use, &c. A large number of specimens have been received from members during the past year, and the Council hope that additional donations will be made to the Museum by members.

The following presentations to the Museum have been received during the past year, and are gratefully acknowledged :—

Specimen.	Presented by—
Two Brass cups showing cracks developed through internal strain.	Midland Railway Co.
The following case of specimens :—	(L. Archbutt, Esq.)
Eleven specimens of corroded and pitted condenser tubes, showing dezincification, &c.	Messrs. The Broughton
Nine specimens of copper tubes and rods, illustrating "Gassed Copper."	Copper Company,
Two specimens of copper rod (overheated).	Limited
Copper rod (severe oxidation).	(F. Tomlinson, Esq.)
Copper rod (perfectly annealed).	
Brass roll from paper-making machine (corroded).	

Specimen.	Presented by—
Specimen of yellow metal bolt (corroded), and a Corroded copper pipe. Also micro-photographs illustrating "gassed" and "overheated" copper and normal tough copper rod.	
Two brass bedstead tubes showing age cracks.	Messrs. Hoskins and Sewell, Limited (Birmingham).
Corroded lead plug.	Midland Railway Co. (L. Archbutt, Esq.)
Corroded condenser tube.	Sir Gerard A. Muntz, Bart.
Two portions of copper tubes from a vinegar plant.	Muntz Metal Co., Ltd.
Portion of a copper singe plate.	(R. M. Sheppard, Esq.)

(b) Library.

During the past year many valuable contributions have been added to the Library, which was commenced two years ago. The Council are much indebted to Sir H. A. Wiggin, Bart., for his gift of £10 10s. for the purchase of bookcases. The Council gratefully acknowledge the following presentations to the Library :—

Title.	Presented by—
American Institute of Electrical Engineers, Proceedings of the, Vol. xxx. No. 11, Nov. 1911; Vol. xxx. No. 12, Dec. 1911; Vol. xxxi. No. 1, Jan. 1912.	E. S. Reid, Esq.
"Assaying and Metallurgical Analysis." By Rhead and Sexton.	Longmans, Green & Co.
Basse & Selve. Jubilee Volume published by the firm on the fiftieth anniversary of their existence.	Herr Wilhelm Ashoff.
British Foundrymen's Association, Proceedings of the, 1910-11.	British Foundrymen's Association.
Concrete Institute, Transactions and Notes of the, Vol. i. (Parts 1, 2, and 3); Vol. ii. (Parts 1 and 2); Vol. iii.; Vol. iv. (Parts 1 and 2); List of Members, &c.	Concrete Institute.
"Geographical Survey of Victoria." Report of Progress by R. Brough Smyth, 1874, 1875.	The Honourable the Minister of Mines, Melbourne, Victoria.
Institution of Electrical Engineers, Proceedings of the, Vol. xlvii. No. 208, July 1911; List of Members, 1910 and 1911.	E. S. Reid, Esq.
Institution of Mechanical Engineers, Proceedings of the, 1899 (Parts 1, 2, 3, 4); 1900 (Parts 1, 2, 3, 4); 1901 (Parts 4 and 5); 1902 (Parts 1, 2, 3, 4); 1903 (Parts 1, 2, and 4); 1904 (Parts 1 and 2); 1905 (Parts 1 and 4); 1906 (Parts 3 and 4); 1907 (Parts 1, 2, 3, 4); 1908 (Parts 1, 2, 3, 4).	The Institution of Mechanical Engineers.

Title.	Presented by—
"Metals in Antiquity." By Professor W. Gowland, F.R.S.	The Author.
"Metalen en Alliages." By Dr. A. Vosmaer.	The Author.
"Notes on the Materials of Motor Car Construction." By A. E. Berriman.	Daimler Co., Ltd.
"Taschenbuch für Eisenhüttenleute.	Wilh. Ernst & Sohn.
"Warship Engineering, 1911." By C. De Grave Sells, M.I.C.E.	The Author.
"Warship Engineering, 1912." By C. De Grave Sells, M.I.C.E.	The Author.

The above books are available for the use of members in the Library attached to the Institute's Offices.

DELEGATES TO CONFERENCES.

In connection with the International Congress of Mining and Metallurgy, Applied Mechanics, and Practical Geology, 1915, Professor W. Gowland, F.R.S., Sir Gerard A. Muntz, Bart., Dr. W. Rosenhain, B.A., and Mr. G. Shaw Scott, M.Sc., were appointed by the Council to act as the representatives of the Institute. The Council have guaranteed the sum of £50 towards the expenses of the Congress.

The Council was represented at the Conference of the Association for the International Interchange of Students, held in London in June 1912, by Professor W. Gowland, F.R.S., and Dr. W. Rosenhain, B.A.

Mr. G. Shaw Scott, M.Sc., was appointed by the Council to act as their representative in connection with the Cornish Meeting of Scientific Societies in Cornwall in July 1912.

At the International Congress of Applied Chemistry, held in New York in September 1912, Dr. W. Rosenhain, B.A., officially represented the Institute.

DOMINIONS ROYAL COMMISSION.

In connection with an inquiry by the Dominions Royal Commission into the supply of non-ferrous metals and ores in this country, the Council have appointed the following committee, with power to add to their number from amongst the members of the Institute: Mr. G. A. Boeddicker (Honorary Secretary), Mr. W. Murray Morrison, Sir Gerard A. Muntz, Bart., Mr. Leonard Sumner, M.Sc., and Professor T. Turner, M.Sc.

ANNUAL DINNER.

The Third Annual Dinner was held on January 16, 1912. There was an attendance of about 150, amongst whom were many distinguished guests, including the Presidents of the allied societies, Mr. Arthur Balfour (the Master Cutler), Colonel Sir Hilary Barlow, Bart., Sir H. F. Donaldson, K.C.B., and Sir Alfred Keogh, K.C.B., LL.D.

Mr. J. W. EARLE said he had pleasure in proposing the adoption of the Report.

Mr. J. P. BEDSON seconded the motion.

The CHAIRMAN thought that it would be agreed that the Report contained a record of steady progress and much useful work. Special interest attached to the part of the Report dealing with the work of the Corrosion Committee. It was at one time hoped that a Report from that Committee would have been received at the present meeting, but it was eventually thought better to wait until more definite results were at hand and further experiments had been carried out, so that the Report that would be presented would ultimately be more valuable. It must not be supposed, simply because a Report had not been presented, that the work was not in progress or was not receiving careful attention. There was now an opportunity if any member wished to speak upon the Report, or to obtain any further information.

No remarks being made, the motion for the reception and adoption of the Report was put and carried unanimously.

REPORT OF THE HONORARY TREASURER.

The CHAIRMAN, as Honorary Treasurer, presented the following Report:—

REPORT OF THE HONORARY TREASURER.

(PROFESSOR THOMAS TURNER, M.Sc.)

For the Year ending June 30, 1912.

It is pleasing to be able again to report that the finances of the Institute are in a satisfactory state. The financial year opened with a credit balance of £456 5s., and closed with a balance, also to credit, of £563 10s. 11d., showing an increase of £107 5s. 11d. This is especially gratifying in view of the fact that the legal costs of the Incorporation of the Institute were paid during the financial year. The sum received from the sale of Journals has increased from £132 18s. 10d. to £159 13s. 1d., and this is satisfactory not merely because it furnishes a source of income, but because it affords definite evidence of the value which is attached to the Journal by interested persons who are in most cases not members of the Institute.

During the year £269 4s. 3d. was expended on the corrosion plant and its working expenses. The balance on July 1 was only £47 7s. 6d., which has since been practically all expended. It is intended to continue these experiments for two or three years longer, and for this purpose an income of about £100 per annum will be required. At a suitable time it is proposed to issue an appeal for further contributions to this fund.

The Capital or Deposit Account has been increased during the year by a sum sufficient to cover the entrance fees received from members on their election to the Institute. The Capital Account, therefore, now contains the whole of the entrance fees which have been received, together with bank interest to date. If it should be found possible each year to add to the Capital Account a sum at least equal to the entrance fees received, a reserve would be gradually accumulated, which would doubtless be of the greatest possible use to the Institute in future.

Allowing for all known liabilities on June 30, 1912, the balance to the credit of the Institute was £548 5s. 8d. This is exclusive of the balance in the Research Fund. There was, in addition, library and office furniture, the contents of the library, and a large stock of Journals.

RECEIPTS.		PAYMENTS.	
To Balance brought forward from last Account—		By Expenses of Meetings	£9 14 9
Lloyd's Bank Limited—		" Journal	513 2 9
Deposit Account	£269 3 11	" MANAGEMENT EXPENSES—	
General	164 2 4	Secretary's Salary and Com-	
Cash in hand of Secretary	17 6 5	mission	£319 4 0
" Treasurer	5 12 4	Rent, Rates, &c.	162 9 0
	£456 5 0	Printing and Stationery	61 17 3
Subscriptions	£1291 6 8	Clerical Assistance	114 6 3
" Sales of Journal	159 13 1	Postages, Travelling Expenses,	
" Sale of Dinner Tickets	45 15 6	and Sundries	94 5 1
" Miscellaneous Receipts	5 15 7		
" Bank Interest, less Charges	2 19 9	Expenses of Dinner	752 1 7
" Interest on Deposit Account	7 6 3	Legal Charges	60 13 6
	1512 16 10	" Furniture Purchased	64 9 10
		"	4 18 6
CORROSION FUND—			1405 10 11
Balance as on 30th June 1911	£241 9 9	" Balance forward—	
Subscriptions	75 2 0	Lloyd's Bank Limited—	
	£316 11 9	Deposit Account	£364 15 2
Less—Amount expended		General	180 6 5
on Corrosion		Cash in hand of Secretary	13 8 10
Plant	£225 0 0	" Treasurer	5 0 6
Expenses of work-			563 10 11
ing, including		CORROSION FUND—	
printing, sta-		Lloyd's Bank Limited	£38 4 7
tionery, &c.	44 4 3	Cash in hand at Liverpool	1 0 5
	269 4 3	" of Secretary	8 2 6
	47 7 6		47 7 6
	£2016 9 4		£2016 9 4

I hereby certify that I have audited the Accounts of the Institute of Metals for the Year ending June 30, 1912, and in my opinion the above Account is a correct statement of the Receipts and Payments for that period.

GEO. G. POPPLETON, CHARTERED ACCOUNTANT,
BIRMINGHAM, LONDON, AND SHEFFIELD.

(Honorary Auditor.)

August 14, 1912.

Continuing, the CHAIRMAN said it would be noticed that the balance was stated as at the 30th June 1912, which was nearly nine months ago, but that was the end of the financial year. Although it did not come in the Report, the members might be interested to know that the financial position of the Institute still remained satisfactory, and he hoped at the end of next year he would be able to say the Institute had had as good a year as last year.

On the motion of Mr. E. L. RHEAD, seconded by Mr. C. F. GAYWOOD, the Report of the Honorary Treasurer was unanimously adopted.

VOTE OF THANKS TO TREASURER.

Mr. W. H. JOHNSON said he had very much pleasure in proposing that the best thanks of the meeting be given to the Treasurer for the very able way in which he had looked after the Institute's accounts. All the members were aware, as business men, that satisfactory finance was the one thing necessary either in a company or an institution. It was a very fortunate moment when, in 1908, the Institute selected as its first Treasurer the Chairman of the meeting, Professor Turner, who seemed to have been born as an accountant in addition to the many professional duties he had to undertake. He had managed the Institute's finances in such a faultless way that he had been always able to present a statement showing a satisfactory balance at the Annual Meetings.

The only thing on which he (Mr. Johnson) felt any hesitation on the present occasion was that he did not think the members of the Institute appreciated the most excellent work that was being done by the Corrosion Committee; in other words, if they appreciated the work better they would have doubled their subscriptions and induced their friends to subscribe. He believed when the Report was issued it would be seen that the work done fully justified the expense, and, what was more, warranted a much larger expenditure for the next few years in investigating that important project. He had much pleasure in proposing that the best thanks of the

Institute be given to the Honorary Treasurer for his kindness in presiding so ably over the financial department of the Institute's work.

The resolution was put and carried with acclamation.

The CHAIRMAN said he was exceedingly obliged to the members for the kind manner in which they had passed the vote of thanks. As a matter of fact, they made it easy for the Treasurer by paying their subscriptions promptly. It was a peculiarity of the Institute that the members as a whole did pay their subscriptions promptly. There were just a few outstanding, but he had been really surprised at the end of the year to find how few outstanding subscriptions there were in comparison with certain other societies in which he acted in a similar capacity.

ELECTION OF OFFICERS.

The CHAIRMAN said that the next matter which came before the attention of the meeting was the election of the Council. Before the result of the ballot was declared it was his duty to report that Sir Henry Wiggin found it necessary to retire from the position of Vice-President. He wrote to the Council a very sympathetic letter, and, as the members had heard while the Report of the Council was being read, Sir Henry was good enough to forward with that letter a cheque for ten guineas for the purchase of additional bookcases for the Library. The Council, in accordance with the rules governing such a casual vacancy, appointed Mr. Boeddicker to act as Vice-President for the residue of the term of office of Sir Henry Wiggin. That led to a vacancy in the Council, which had been filled by the election of Mr. Alexander Cleghorn, of Glasgow, who took the place of Mr. Boeddicker for the remaining term of office of Mr. Boeddicker's service as an ordinary member of the Council. In accordance with the regulations, it was necessary that Mr. Cleghorn's election should be approved, and he therefore had much pleasure in proposing Mr. Cleghorn's re-election as an ordinary member of the Council.

Mr. G. A. BOEDDICKER seconded the resolution, which was carried unanimously.

The CHAIRMAN called upon the Secretary to announce the result of the ballot for the election of members to replace the retiring President, two Vice-Presidents (including the Honorary Treasurer), and eight Members of Council, the list as read being as follows :—

President.

Professor A. K. HUNTINGTON, Assoc.R.S.M.

Vice-Presidents.

W. H. JOHNSON, B.Sc.	. . . . .	Manchester.
Professor T. TURNER, M.Sc. (Hon. Treasurer)		Birmingham.

Members of Council.

Professor A. BARR, D.Sc.	. . . . .	Glasgow.
T. A. BAYLISS	. . . . .	King's Norton.
G. T. BEILBY, LL.D., F.R.S.	. . . . .	Glasgow.
CLIVE COOKSON	. . . . .	Newcastle-on-Tyne
ARNOLD PHILIP, B.Sc., Assoc.R.S.M.	. . . . .	Portsmouth.
Sir WILLIAM E. SMITH, C.B.	. . . . .	London.
LEONARD SUMNER, M.Sc.	. . . . .	Manchester.
CECIL H. WILSON	. . . . .	Sheffield.

VOTE OF THANKS TO COUNCIL.

Dr. G. D. BENGOUGH said it afforded him very much pleasure to move a hearty vote of thanks to the Council for the excellent work that they had performed during the past year. Every single member of the Council was known to be an exceedingly busy man, but in looking through the Report of the Council which had been presented earlier in the meeting, he was sure the members would appreciate the large amount of time they must have given to the work of the Institute. Even the writing of a Report of that kind was a very slow and long process. The members owed a very great debt of gratitude to the Council for all the work they had done during the past twelve months, and he therefore had great pleasure in proposing a hearty vote of thanks to them for their services.

Mr. E. L. RHEAD, in seconding the motion, said all the members felt very keenly that the members of the Council were extremely alive to the interests of the Institute, and did all in their power to make it a success. The remarkable progress that had been achieved in the past four years was sufficient evidence of the success that attached to the work that they had done.

The resolution was put to the meeting by Dr. BENGOUGH, and carried unanimously.

The CHAIRMAN, on behalf of the Council, thanked the members very sincerely for the resolution they had just passed. The Council did take their duties seriously, and on that account a good deal of useful work had been done, and the Institute was no doubt making steady and substantial progress. There was, he thought, one little matter in which they might look for help from the general body of members, and that was in connection with the discussions. The discussions were apt to be carried on by a limited number of speakers upon whom the Institute generally relied. There were a number of men, particularly younger men, in the Institute who had both scientific knowledge, a certain amount of experience, and also, he believed, the capacity for making themselves understood. He hoped that the discussions would not be left in the future so much in the hands of a few older members—(he was afraid he had been one of the greatest sinners in that respect in the past, as he had spoken upon many of the papers)—but that the young members would come forward and take their share in the work.

ELECTION OF MEMBERS.

The SECRETARY read the following list of names of candidates who had been duly elected members of the Institute as a result of the ballots taken in December 1912 and February 1913:—

NAME.	ADDRESS.	QUALIFICATION.	PROPOSERS.
Ash, Percy Claude Matchwick	10 Broad Street, Golden Square, W.	Engaged in the treatment of precious metals for dental pro- fession	G. Matthey. A. J. Webb. E. V. Jarry.
Belaiew, Nicolai, T.	Chemical Labora- tory, Michael Ar- tillery Academy, St. Petersburg	Lecturer in Metal- lurgy and Chem- istry. Captain, Artillery of the Guards	W. Rosenhain. G. A. Boeddicker. A. K. Huntington.
Borchers, Wilhelm, Dr. Ing. Ph.D.	Ludwigsallee 15, Aachen, Germany	Professor of Metal- lurgy	W. Rosenhain. A. K. Huntington. T. Turner. K. Fraser.
Cardozo, Henri Alexandre	54 Rue de Prony, Paris	Director of Electro Metallurgical Co.	W. Gowland. A. K. Huntington. T. Turner.
Gibson, Heseltine, B.Sc., (<i>Student</i>)	9 Barnsley Road, Edgbaston, Bir- mingham	Metallurgist to the British Aluminium Company	O. F. Hudson. A. G. C. Gwyer.
Goldberg, Harry, (<i>Student</i>)	Aluminium Casting Co., Detroit, Mich., U.S.A.	Chemical Engineer	H. W. Gillett. W. M. Corse. H. M. Boylston.
Groves, Clarence Richard, M.Sc.	Gamble Institute, St. Helens, Lancs.	Lecturer in Metal- lurgy	T. Turner. H. I. Coe. O. F. Hudson.
Heath, William Stanley (<i>Student</i>).	Heather Rocks, Stockton Brook, Stoke-upon- Trent	Assistant Analyst, the British Alum- inium Company, Ltd.	T. Turner. A. G. C. Gwyer. O. F. Hudson.
Hoyt, Samuel Leslie.	Hewaldstr. 2 III. Berlin, Schone- berg, Germany	Metallographist	W. Guertler. C. A. F. Benedicks. W. Rosenhain.
Jennison, Herbert Charnock	P. O. Box 348, An- sonia, Conn., U.S.A.	Engaged in Manu- facture of Non- ferrous Metals	W. H. Bassett. J. A. Capp. W. M. Corse.
Kirkaldy, William George.	99 Southwark St., S.E.	Engaged profession- ally in experimen- tal work and the testing of metals	A. A. H. Scott. B. Blount. F. W. Harbord.
Lambert, Wesley, A.K.C.	55 Plumstead Com- mon Road, S.E.	Metallurgist, late Chief Metallurgist Royal Gun Fac- tory, Woolwich	A. K. Huntington. W. Rosenhain. T. Turner.
Lyon, Professor Dorsey Alfred	Box 83, Oakland Station, Pittsburg, Pa., U.S.A.	Consulting Metal- lurgist. In charge of Metal- lurgy Section, U.S. Bureau of Mines	F. W. Harbord. E. F. Law. E. G. Constantine.
Marshall, Frederick William	Admiralty, White- hall S.W.	Engineer Com- mander, Royal Navy	Sir H. J. Oram. G. G. Goodwin. Henry R. Teed.
Mayo, Charles Robert	Alderman's House, Bishopsgate, E.C.	Consulting Engineer	F. Tomlinson. H. C. H. Car- penter.
Player, William	54 Calthorpe Road, Edgbaston, Bir- mingham	Dir. and Sec. The Hall Street Metal Rolling Co., Ltd.	F. W. Harbord. T. V. Hughes. A. D. Keeling. J. W. Earle.

NAME.	ADDRESS.	QUALIFICATION.	PROPOSERS.
Pollard, William Branch, B.A.	Beitel-Barrache, Bulak Dakvuv, Egypt	Chemist	H. Garland. A. E. Seaton.
Rejto, Professor A.	Budapest, Muegye- tem, Hungary	Professor of Tech- nology, Member, Royal Hungarian Academy of Science	Sir H. J. Oram. W. Rosenhain. W. Gowland. A. K. Huntington.
Rider, Joseph Jack- son	"Roxton," Chester Road, Erdington, Birmingham	Expert in Metals	W. H. Johnson. B. S. Harlow.
Rosambert, Charles	Metallwerk, Man- fred Weiss, Cépel, near Budapest.	Director of Metal Works	W. G. Hanna. W. Rosenhain. W. Gowland. A. K. Huntington.
Saposhnikow, Alexis	Zabalkansky pr 9, St. Petersburg, Russia	Professor of Chemis- try	W. Rosenhain. A. K. Huntington.
Sauveur, Professor Albert	20 Elmwood Avenue, Cam- bridge, Mass., U.S.A.	Professor of Metal- lurgy and Metal- lography, Har- vard University	Sir G. Muntz, Bt. H. O. Hofman. Henry Fay. H. M. Boylston.
Sitwell, Norman Sisson Hurt	Cox & Co., Charing Cross, S.W.	In Indian Or- nance Dept., Captain, Royal Artillery	R. F. Hartley. J. J. Edwards. E. I. Thorne.
Sjögren, Justus Fredrik	30 Easy Row, Bir- mingham	Metal Agent and Merchant	T. A. Bayliss. Harry Jacobs.
Tiemann, Hugh Philip, B.S.	Carnegie Building, Pittsburgh, Pa, U.S.A.	Metallurgist, Car- negie Steel Co.	T. Turner. H. M. Howe. W. Gowland.
Weiss, Eugen V.	Andrassy-ut 116 Budapest, Hun- gary	Engineer	A. K. Huntington. W. Rosenhain. A. E. Seaton. W. Gowland.

The CHAIRMAN said the list of members that had just been read would be ballotted upon. He was sure the members would notice with satisfaction that it contained the names of eminent metallurgists, not only in this country but on the Continent and in America.

ELECTION OF AUDITOR.

The CHAIRMAN said that the next matter was the election of the Auditor. Mr. G. G. Poppleton had served the Institute as Honorary Auditor from its commencement. Mr. Poppleton was a member of the Institute, and his work as Auditor was extremely efficient. He therefore moved as a comprehensive resolution that Mr. Poppleton be thanked for his

work during the past year, and that he be asked to continue to act as Auditor during the following year.

Mr. W. H. JOHNSON seconded the motion, which was carried unanimously.

The CHAIRMAN said only one other duty remained for him to perform, and that was the very pleasant one of asking the President-Elect, Professor Huntington, to take the Chair. It would be unwise for him in London to endeavour to introduce Professor Huntington to a metallurgical audience. He had been connected with metallurgy for so many years; he had been so well known for his interest in different branches of the subject, for his published works, for his original investigations, and for his labours in connection with the older kindred Institute, the Institute of Mining and Metallurgy, of which he had acted as President, and was so highly respected, that the members felt sure that, having undertaken the duty of presiding over the assemblage, that duty would be efficiently performed, and that the Institute might look forward to a very successful year under his Presidency.

Professor TURNER then vacated the chair, which was taken for the remainder of the meeting by the President (Professor A. K. Huntington).

VOTE OF THANKS TO RETIRING PRESIDENT.

The PRESIDENT said it afforded him much pleasure to know that his first act as President was to move a vote of thanks to the retiring President, Professor Gowland. All the members regretted very much indeed that they did not see more of the late President during his term of office. Unfortunately his health was not of the best, and he had to go away for a good part of the year; but they all very much appreciated the work that he was able to carry out. He gave an interesting Presidential Address, and an equally interesting May Lecture, while he did much useful work for the Institute in a good many ways. He had much pleasure in proposing a cordial

vote of thanks to Professor Gowland for his services during his Presidency of the Institute.

Mr. G. A. BOEDDICKER, in seconding the motion, said he had the pleasure of coming in contact with Professor Gowland at a great many of the Institute's meetings, and he was particularly struck by his ability, his unfailing courtesy, his almost excessive modesty, and his general good temper in carrying on the business of the Institute. In seconding the motion he again expressed the wish, which he was sure was fully shared in by the members, that Professor Gowland would soon return to this country in greatly improved health.

The resolution was then put to the meeting, and carried by acclamation.

The PRESIDENT said he desired to propose a vote of thanks to Professor Turner for occupying the chair at that meeting in the absence of Professor Gowland.

The resolution of thanks was carried by acclamation.

INAUGURAL ADDRESS.

The PRESIDENT delivered his Inaugural Address, at the close of which

Sir GERARD A. MUNTZ, Bart. (Past-President), said the privilege fell to his lot of proposing a hearty vote of thanks to the President for the very interesting and instructive address he had just delivered. The nature of the address pointed, he hoped, to the nature of the work that Professor Huntington was going to do during his term of office as President—work of a good, sound, common-sense nature, of steady progress and careful supervision. The President had given in the course of his address a description of the formation of the institutions similar to their own, with all of which he (the President) had been connected, which showed that the new President had had an experience the benefit of which

ought to fall upon the Institute of Metals. The President suffered, like his friend Mr. Boeddicker, from a superfluous amount of modesty, but he trusted the members would be able to "draw him out," for he knew that Professor Huntington could do great services for the Institute during his term of office. He had very great pleasure in moving a hearty vote of thanks to the President for his able and interesting address.

Mr. T. A. BAYLISS, in seconding the motion, said he hoped the forecast which the President gave in his address in regard to the Institution of Mining and Metallurgy would prove equally true in the case of the Institute of Metals in the coming years. The members were delighted to see Professor Huntington as President of the Institute, and looked forward with the greatest possible pleasure to a full year of good work for an institution which was appreciated by one and all.

The resolution having been carried by acclamation, and the President having thanked the meeting for the hearty manner in which it had been passed, the meeting was adjourned at 4.30 P.M. until 10.30 A.M. the following morning, Wednesday, March 12, 1913.

SECOND DAY'S PROCEEDINGS.

WEDNESDAY, *March 12, 1913.*

At the adjourned meeting, which was presided over by the President (Professor A. K. Huntington, Assoc.R.S.M.), papers were read by Mr. Alexander Siemens (London); Mr. A. Philip, B.Sc. Assoc.R.S.M. (Portsmouth); Dr. G. H. Bailey (Kinlochleven); and Mr. O. F. Hudson, M.Sc. (Birmingham). In the absence of the authors, the Secretary read papers by Mr. G. H. Gulliver, B.Sc. (Edinburgh); and Messrs. H. S. Primrose and J. S. Glen Primrose (both of Glasgow).

Each paper was followed by a discussion, a hearty vote of thanks being accorded in each case, on the motion of the Chairman, to the respective authors.

CONCLUDING BUSINESS.

The CHAIRMAN moved the following resolution:—"That the best thanks of the Institute be and are hereby tendered to the Council of the Institution of Mechanical Engineers for their courtesy in permitting the use of their Hall for the purpose of this Annual General Meeting."

Professor T. TURNER, in seconding the motion, said the rooms of the Institution were very convenient for the purpose, despite the discomfort due to the present building operations; and the members were much indebted to the Council of the Institution of Mechanical Engineers for the practical sympathy they had shown to the Institute in many ways.

The resolution was put, and carried unanimously.

Mr. G. A. BOEDDICKER, in moving a hearty vote of thanks to the President for the excellent manner in which he had presided over the business of the meeting, said that Professor Huntington had proved an ideal Chairman. He had allowed the speakers reasonable margin; he always kept them in good humour, and kept the whole meeting going splendidly.

Mr. E. L. RHEAD seconded the motion, which was carried with acclamation.

The PRESIDENT thanked the members very heartily for their kind vote of confidence in him. It gave him great pleasure to preside over the meetings, which had gone off very smoothly, and he hoped successfully.

The proceedings terminated at 4 P.M.

PRESIDENTIAL ADDRESS.*

BY PROFESSOR A. K. HUNTINGTON, A.R.S.M.
(KING'S COLLEGE, UNIVERSITY OF LONDON).

IN the early years of the establishment of a new institution, it is usual in a Presidential Address to call attention to the lines on which it is considered the institution could be most advantageously developed. Considerable assistance in this direction may result from a study of the purposes and progress of other institutions on somewhat similar lines and of longer standing.

It so happens that the Institution of Mining and Metallurgy, in the foundation of which I helped, and of which I became the second President, has recently celebrated its twenty-first anniversary. It has not unnaturally occurred to me to look up my Presidential Address before that institution on March 21, 1894, and see how far the efflux of time has justified what I said on that occasion, and what guidance we may obtain from the career of the Institution of Mining and Metallurgy. One of the first sentences to catch my eye was: "Like all infants, its fortune will depend largely on those who have its early guidance. It may have enormous potential energy, but potential energy is a dangerous thing unless well directed. The same little packet of explosive, according as it is properly applied in a mine, or improperly applied to, say, the Royal Observatory at Greenwich, may do much useful work or incalculable mischief." (It would appear I was unconsciously forecasting the advent of Suffragettes.) The Institute of Metals has been extraordinarily fortunate in this matter of its early guidance, and I am certain that I am only expressing the unanimous feeling of the members in saying that the quite exceptional rate of progress of the Institute of Metals is largely due to the well-directed energy and unfailing tact of its first presidents, Sir William White† and Sir Gerard Muntz. These gentlemen have still further increased the

* Delivered at Annual General Meeting, London, March 11, 1913.

† Deceased, to the great loss of the Institute, since this was written.

obligation the Institute is under to them by continuing to give much of their valuable time to its affairs whenever any benefit could result from their doing so. The prestige of the Institute has been well maintained also by its later President, Professor Gowland, who unfortunately, although possessing all the capacity and will to do so, has been prevented by failing health from attending to the affairs of the Institute as much as he desired. The task I have before me, although in some respects rendered easier, is in others made more difficult by the exceptional ability of your past Presidents. I am consoled, however, to some extent, by the thought that you have had opportunities of sampling my conduct in the chair during the past year, and if I shall prove but up to sample, I may be said to have fulfilled my contract. I hope, however, that it is unnecessary for me to say that I have the interests of this Institute very much at heart, and that I will try my utmost to promote them during my year of office.

At the time of my address to the Institution of Mining and Metallurgy, the Iron and Steel Institute had been in existence twenty-five years. It was founded in 1869. The then Duke of Devonshire was its first President, and he gave a most able address, pointing out the advantages of co-operation among those engaged in a common pursuit. This enlightened advice has been followed by steel manufacturers with great benefit to all concerned. About twelve years after the inauguration of the Iron and Steel Institute, ten old School of Mines men met under the chairmanship of Sir Warrington Smyth to endeavour to form an institute on somewhat similar lines for the other metals. We, however, failed, and it was only after the lapse of about ten years that, with the help of the editor of the *Mining Journal*, success in this direction was achieved. It is of interest, as showing how many wheels within wheels there are in these matters, that the very circumstance which helped us to launch the Institution of Mining and Metallurgy, viz. the support of the *Mining Journal*, stood in our way later on. Many people then would not join the Institution because they objected to its being connected with a newspaper. As a matter of fact the only connection between the *Journal* and the Institution

had been that the former had given publicity to the necessity for the latter. In the course of time these early difficulties were lived down, and the Institution has become the powerful body we know to-day, numbering some 2500 members. Even then the Institution of Mining and Metallurgy only concerned itself with a part of the science and art of metallurgy, viz. that dealing with the extraction of metals from their ores. That part which has to do with the working and uses of metals and alloys was not discussed or referred to in the Institution of Mining and Metallurgy at all. That Institution does in fact differ from the Iron and Steel Institute in an important way. The latter practically does not concern itself with mining operations. It has to do with the smelting of iron ores into various grades of pig iron, the conversion of pig iron into the various kinds of steel, and the subsequent treatment and behaviour of such steels when in use. These few words give but a feeble idea of the immensity and diversity of the subjects which fully occupy the splendid energy of the Iron and Steel Institute. On the other hand, the Institution of Mining and Metallurgy specializes in mining and the extraction of non-ferrous metals from their ores—mainly, however, at mines; but it does not concern itself with the subsequent treatment and behaviour in use of these metals, nor would it ever have been likely to do so, the field it already covers being as much as any institute could satisfactorily cope with. It was the knowledge of this condition of things which prompted me, when the Faraday Society was formed, to include Metallography and electric furnaces in the scope of the work to be considered by that body. The Faraday Society, although doing admirable work, is hardly in a position to deal adequately with Metallography.

This review should make it amply clear that not only was there room for an institution having the objects of the now existing Institute of Metals, but that such an association was urgently required, having regard to the great progress made by the Iron and Steel Institute in such matters, and their almost complete neglect in respect to the non-ferrous metals and alloys by other bodies. It is very gratifying that the Institution of Mining and Metallurgy has accepted in a

most friendly way the position taken up by the Institute of Metals.

Referring again to my address in 1894, I find I said: "The progress in the iron and steel industries in the last twenty-five years has been extraordinary, and I have no hesitation in saying that a large share of it is due to the existence of the Iron and Steel Institute. The members of those industries are no longer working against one another in a very narrow spirit, being afraid to confide their ideas one to another lest they should give a competitor an advantage. All this narrowness has disappeared, and now members visit one another's works and discuss everything concerning them at every opportunity. *As in everything else, the best man wins in the long run, whilst the rest of the world are benefited by more rapid progress.*" Nearly twenty more years have passed since those words were written. The same enlightened policy has been pursued in these industries; still further great progress has been made; the world has benefited by it and the best men, as ever will be the case, have come to the front.

At the time this address was given I had in mind many works in this country where metals were smelted and refined, which preserved secrecy as to their doings, and would admit no one to their works. Now, notwithstanding that the Institution of Mining and Metallurgy has been in existence twenty-one years, these same works, for the most part, maintain the same attitude; they contribute nothing whatever to that Institution. The Institution has had its time fully taken up with metallurgy as carried out in direct connection with mines, and probably has given the works in question hardly a thought, and judging from the experience of the Institute of Metals, if they had acted otherwise they would probably have only received a rebuff. I do not think the Institution of Mining and Metallurgy would object to these works coming under the Institute of Metals. Perhaps in time they will come into line, but the time is not yet. I am entirely of the opinion expressed by the late Sir William White on a former occasion; each individual must be left to contribute as much or as little information to the Institute as he may think fit. The way in which this Institute has progressed during the few years

it has existed leaves no doubt in my mind that the non-ferrous industries will respond to its stimulus, just as the iron and steel industries did in the case of the Iron and Steel Institute.

In a review of this kind it would be unfair to ignore the Society of Chemical Industry. Founded in 1881, it took all manufacturing chemistry under its wing. Its journal was divided into a number of sections, one being set aside for Metallurgy. Subsequently there was a section for Electro-chemistry and Electro-metallurgy. More recently Electro-metallurgy has been separated from Electro-chemistry and added to the section on Metallurgy. There can be no doubt that the Society of Chemical Industry has done good work in the field our Institute covers, and we should be grateful to it; at the same time the Society of Chemical Industry would be the first to admit that the time is ripe for specializing more fully in this subject than they are in a position to do. Doubtless they will continue to have a section for Metallurgy for the information of their members, and in this the existence of our Institute will benefit them, as in this subject they have depended for the most part on abstracts, although from time to time they had original papers. I myself contributed two short papers, at the request of Sir Frederick Abel, to the first annual meeting held by the Society of Chemical Industry in 1882 at Manchester under the presidency of Sir Henry Roscoe. One was on the "Mexican Amalgamation Process for Silver" and the other on "Nickel." I mention this because it comes back to my mind that in the paper on the silver process it was shown that certain reactions, which were said to take place in a process investigated by a well-known French chemist, were really due to a reagent used in the investigation, and had no existence in the process at all. It is not often in chemical work that a mistake of this kind occurs, but in micrographic work it may quite easily happen, if extreme care is not exercised and observations checked by repetition and the use of different methods as far as possible. To illustrate this, I may say that recently in making an examination of a piece of metal a slice was cut and carefully polished; it was then bent and etched. Very

marked slip-bands appeared, which apparently threw an important light on the matter under investigation. Fortunately I was aware that alloys consisting mainly of copper-zinc and in the β phase were particularly liable to the formation of slip-bands on being sawn or filed, no matter how carefully. It was in fact found that the slip-bands, although very marked, being in two directions at right angles, forming isolated squares in some cases, were only superficial, and not in any way due to the bend the metal had received. In this case what might have been taken for an explanation of the trouble was due to the original mechanical treatment in cutting the slice for examination. Similarly, in etching it is easy to be misled unless the nature of the etching is suitably adjusted to the particular point being looked for, say the "cores" in Plate II., so that for the same specimen it may be necessary to apply a variety of etchings. These remarks may appear very elementary, but from considerable practical experience I believe it will be some years yet before they will be altogether uncalled for in speaking of micrography.

It must be remembered that Metallography for practical purposes has only come into existence within the last fifteen years or so. The difference it has made in understanding what happens to metals and alloys in course of manufacture and in use is incalculable. Looking back, it is easy to appreciate that the knowledge to be gleaned from a chemical analysis of an alloy is as nothing compared with what can be obtained by the means now available for studying the internal condition and structure of metals and alloys, when their composition is varied, and they are subjected to suitable, or unsuitable, mechanical and heat treatment. In dealing with copper-zinc alloys in the α - β range it has been the practice for some years in my laboratory to use a method of micrographic mensuration occupying quite a short time where formerly a chemical analysis would have been required. If the Council should think it of sufficient interest to the Institute, I shall be pleased to communicate a short description of this method at some future meeting.

It is really due to the rapid growth of Metallography and

Chemical Physics that this Institute came into existence when it did.

On several occasions your attention has been called to the important part taken by Professor Carpenter and Mr. Johnson in the inception and founding of this Institute. Professor Carpenter constantly gives his attention to the working of the Corrosion Committee, and devotes a great deal of time to the Institute in various ways. We all know and welcome his surprising energy in supplying us with papers of the most up-to-date character. Sir Gerard Muntz, who might have been excused if he had retired behind the scenes for a time and taken a rest, has shown unabated zeal in the cause of the Corrosion Committee by remaining its chairman and giving it the great advantage of his practical knowledge and business ability.

As will be seen from the Report of the Council, this Committee is in active operation. A good start has been made with the work, which is being carried out under the able supervision of Dr. Bengough. There is already every indication that this work will be not only of considerable interest, but also of great practical utility. Although Dr. Bengough is giving a great deal of his valuable time gratuitously, an investigation of this kind cannot be carried out without a substantial monetary backing. It will be the shipping industry which will ultimately reap the benefit of the results, and it is only reasonable that those engaged in that industry, which is now in a particularly prosperous condition, should be urged to contribute liberally to the requisite funds. The most friendly relations exist between this Institute and the various institutions representing shipping interests, but for the most part the hands of these institutions are tied in the matter of voting funds for such a purpose. It is therefore to the individual members of these bodies that our appeal must be addressed, and I feel sure that it will not be in vain.

It is gratifying to be able to report that the Library and Museum, under the able chairmanship of Mr. Boeddicker, our new Vice-President, who fills the vacancy made by Sir Henry Wiggin retiring from inability to attend the Council meetings, has made satisfactory progress. The collecting together of specimens illustrating the behaviour of metals and alloys

under various conditions is an object worthy of the fullest encouragement, and likely to be prolific of much good in more than one direction. Notably, it becomes a starting-point for discussions between members, and inevitably leads to mutual enlightenment. For this, if for no other reason, it would be desirable to obtain better accommodation than the Institute has at present; but we must cut our coat according to our cloth. It is only by a considerable increase in members that we can be in a position to do effectively what is needed and would be most beneficial to the community.

On the principle that "Nothing succeeds like success," our membership ought to go up by leaps and bounds. This is but the fifth year of our existence, and our membership is 606. At the same period of its existence the Iron and Steel Institute had 587 members, whilst the Institution of Mining and Metallurgy reached practically the same figure (585) in its seventh year. The membership of the Iron and Steel Institute increased to 1206 in its fourteenth year, and to 1427 on attaining twenty-one. The corresponding figures for the Institution of Mining and Metallurgy were 1324 and 2258. Our prospects are of the brightest.

Both the Iron and Steel Institute and the Institution of Mining and Metallurgy have a considerable number of members either resident abroad or belonging to foreign nations. That foreigners become members of our institutions is in itself a very healthy sign. We are indebted to Dr. Rosenhain, who, in consequence of his official status and his recognized scientific ability, has been in a position to help us much in this direction. I am pleased to announce that our Autumn Meeting will take place this year at Ghent. This, it is hoped, will have the effect of increasing our foreign membership.

I have had an analysis made of the countries from which our members are drawn. It is both interesting and instructive.

By a coincidence the membership in the whole of America exactly equals that of Europe, excluding the British Isles. One would like to see Canada represented by a larger number, but Canada from a manufacturing point of view is in its infancy. Still it has engineers, and there is every indication that its progress in the next few years will be stupendous.

Analysis of Countries of Residence of Members.

<i>Africa.</i>							
Transvaal	.	.	.	.	.	.	7
West Africa	.	.	.	.	.	.	1
Egypt	.	.	.	.	.	.	1
							— 9
<i>America.</i>							
Brazil	.	.	.	.	.	.	1
Canada	.	.	.	.	.	.	3
United States	.	.	.	.	.	.	37
							— 41
<i>Asia.</i>							
India	.	.	.	.	.	.	7
Japan	.	.	.	.	.	.	1
							— 8
<i>Australasia.</i>							
New South Wales	.	.	.	.	.	.	1
Queensland	.	.	.	.	.	.	1
Victoria	.	.	.	.	.	.	1
							— 3
<i>British Isles.</i>							
England	.	.	.	.	.	.	430
Ireland	.	.	.	.	.	.	2
Scotland	.	.	.	.	.	.	55
Wales	.	.	.	.	.	.	17
							— 504
<i>Europe (excluding British Isles).</i>							
Belgium	.	.	.	.	.	.	6
France	.	.	.	.	.	.	6
Germany	.	.	.	.	.	.	12
Gibraltar	.	.	.	.	.	.	1
Hungary	.	.	.	.	.	.	4
Russia	.	.	.	.	.	.	1
Spain	.	.	.	.	.	.	6
Sweden	.	.	.	.	.	.	4
Switzerland	.	.	.	.	.	.	1
							— 41
Total number of members in January 1913							606

If I may be permitted, I will once more refer to my address of 1894. I said: "As having an important bearing on the mining and metallurgical industry, another case of great want of national foresight may be instanced. I refer to our colonial policy—if policy it can be called, for it has consisted of a masterful rather than a 'masterly inactivity.' Yet the position of our country, now second to none the world has known,

must in the near future be determined by its relations to its colonies and dependencies. This is seen by all at home who are not immersed up to the eyes in petty party politics, blinding them to all else. Other nations are not only fast tending to supply the greater part of their own requirements, but are even trying to oust us in our own colonies.

"The foresight up to the present has been all on the part of the colonies themselves. The building of the Canadian Pacific Railway—to take but one instance—will be a lasting memorial of the enterprise and sagacity of its leaders. It is they, again, not we, who are taking active steps to brace the British Empire round with the only bonds which can ensure its existence and continuance—direct and cheap communication throughout by rail and steamer, and by telegraph and cable."

I venture to think that this is a fair forecast of what has happened and is happening. In the near future Canada will be one of the greatest factors in the world's affairs and doubtless a strong supporter of this Institute until she shall be in a position to have one of her own and even afterwards.

The "Analysis of Countries" will repay another glance. It will be seen that Germany has twice as many members as any other country in Europe. It is the Writing on the Wall. She neglects nothing which can be helpful in establishing and maintaining her commercial supremacy, an altogether patriotic and worthy proceeding on her part, which we should be the last to blame her for. The number of German members is a compliment to this Institute which other nations might do worse than follow.

It is to the credit of our country that it inaugurated the type of institution represented by the Iron and Steel Institute, the Society of Chemical Industry, the Institution of Mining and Metallurgy, and our own. Its supremacy in this respect is acknowledged by all other nations, for they have nothing to equal them, and freely become members of them. The most remarkable case of all is that of the Society of Chemical Industry, which actually has sections abroad. It has at present sections in New York, New England, Canada, and Sydney, New South Wales, and its President for this year is

Dr. Bogert of the United States of America. This is indeed a breaking down of the walls; one touch of science making us all akin.

Our Institute, departing from the practice of the Iron and Steel Institute and the Institution of Mining and Metallurgy, is following the lead of the Society of Chemical Industry to the extent of having sections in this country, a most admirable start having been made in Birmingham under the Chairmanship of Mr. Boeddicker, who in a most modest and unassuming way does so much useful work for this Institute. This section has been so active and successful, that it is to be hoped that others will be formed at, say, Liverpool or Manchester, in the neighbourhood of which there are many works, and at Sheffield, which, although a stronghold of steel, has many other industries.

A further analysis has been got out to supplement that already given. It sets forth the number of journals sold in various countries apart from the journals sent in the ordinary course to members. This analysis is also very instructive. It shows the large number of our journals taken by the United States of America, and the prominent position of Germany is still further emphasized, France, however, showing up rather better than in the first analysis. This analysis of journals sold is, however, somewhat imperfect, because many of the journals bought by booksellers in this country are destined for abroad, and this Institute has no means of ascertaining what becomes of them, so they are included in those put down against England.

Analysis of "Journals" Sold in Various Countries.

Africa.

Transvaal	6
Egypt	3

America.

Brazil	4
United States	101

Asia.

Japan	9
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<i>British Isles.</i>						
England	421
Scotland	22
<i>Europe.</i>						
Belgium	6
France	15
Germany	37
Holland	.	.	.	.	.	8
Russia	.	.	.	.	.	7
Spain	.	.	.	.	.	3
Sweden	.	.	.	.	.	9
<i>Australasia.</i>						
Queensland	.	.	.	.	.	8

In any case, that so many journals have been sold is highly satisfactory. People may join the Institute for various reasons, but they are not likely to buy the journal for any reason other than that they consider it contains valuable information which is likely to be of use to them as manufacturers, users, or professional men.

It occurred to me to examine as to the percentage of the three classes of which our Institute is made up. It was found to be as follows:—

Description.	Number of Members.	Per Cent.
Manufacturers	225	37
Users	206	34
Professionals	175	29
Total	606	100

Having done that, I next proceeded to obtain from the Secretary the information contained in the following table:—

Number and Percentage of Papers Contributed by Members since the Foundation of the Institute.

Description.	Number of Papers.	Per Cent.
Professional members	58	75 $\frac{1}{2}$
Users	12	15 $\frac{1}{2}$
Manufacturers	7	9 $\frac{1}{4}$

I had no idea that the percentages of the numbers of members in the three classes forming the Institute would come out as near one another as they do. A very different tale is told, as might be expected, by the table of papers contributed. The users are setting the manufacturers a good example, which it is to be hoped they will not be slow to follow.

The position between manufacturers and users is always a somewhat delicate one. If the manufacturer makes inquiries of the user as to how the material he has supplied is behaving, the user might turn round and say, "Dear me! what is the meaning of this! Evidently he has no confidence in the material himself, notwithstanding all he has said about it." So the manufacturer waits till the user goes for him, and, in the very human desire to save his own skin, he probably retorts that what has gone wrong is due to improper usage. In ninety-nine cases out of a hundred he is very likely right. What is required is more mutual confidence. If users would realise that others are quite as straightforward as themselves a great step would have been achieved. It may be taken for certain that, except in the case of a few people in a small way of business, manufacturers are acting straightforwardly and doing their very best to build up or maintain a good reputation. Manufacturers are at an enormous disadvantage in not being able to obtain readily and continuously reliable information as to how their material is behaving and, above all, to what conditions it is really being subjected in use. If users would invite manufacturers to send a representative at reasonable intervals to see and discuss the behaviour of the material they have supplied it would be greatly to the gain of all concerned.

Speaking as a professional man who has had a great deal to do with works for very many years, I say that the greatest difficulty I have had to contend with has been the obtaining of reliable information from users. It is not merely that they will not give it, but more frequently they have not got it. All sorts of trouble and mistakes result from this state of things. Everybody is accustomed to think he is competent to observe, whereas the actual fact is that very few people are competent to observe. To observe accurately requires a mental training

from early youth onwards, which very few people hitherto have had. Now that metallography and physical chemistry are taught at so many institutions there will not in future be the same excuse that there has been, and young engineers and works' chemists should be required to have a competent knowledge of these subjects. This is a direction in which the third components of our Institute should play an important part. They are also in the position very often to take the part of the honest broker and bring the manufacturer and user into sounder relations the one with the other, by pointing out that the users have everything to gain by carefully and systematically observing what is happening to the metals and alloys they are concerned with, and giving this information in a friendly spirit to the manufacturer with the object of helping him to meet their requirements, which, from a business point of view, if no other, he will be anxious to do. In doing this the users themselves will also learn a great deal, which will cause them to realize that the old adage, that prevention is better than cure, has something to be said for it, and most certainly leads to economy and peace of mind.

I am sure the members appreciate at its full value the example set by Mr. George Hughes notably, and by others, in bringing suitable papers on behalf of the users before us.

We have reviewed the relations of the three components of this Institute to one another. It remains to examine the position this Institute occupies in relation to the public, for though it is not definitely stated as one of the objects of the Institute or referred to in previous presidential addresses, every institution of the kind possessing a charter undoubtedly has obligations to the public. We enjoy certain privileges and recognition through the goodwill of the public, and the least we can do in return is to safeguard the interests of the public in every way in our power. This may be done in many ways. The more fully we recognize our obligations in this direction, the more influential for good will become our Institute in relation to Government departments and other institutions throughout the world.

I recall to mind a case in my personal experience in which, had this Institute then existed, the matter might have

been looked into and an authoritative statement made which would have relieved the mind of the public and saved railway engineers much anxiety. A somewhat serious explosion in a locomotive had taken place which was by some attributed to a copper-zinc alloy having been used for the stays in the fire-box. The old scare as to such alloys becoming brittle in use, especially in the presence of vibration and a temperature higher than the atmospheric, was raised. As a result many railway engineers who had been using a copper-zinc alloy for this purpose, though not the alloy in question, were afraid to put any more in. Personally I did not think it at all probable that the trouble had arisen from any change in the crystalline structure of the metal itself whilst in use. Through the courtesy of Messrs. the Caledonian Railway Company and J. Stone & Company, I am in a position to lay before you the results of an investigation I have recently made in this matter. Some stays from the firebox of a locomotive working at 160 lbs. pressure which had been in use sixteen years were sent to me. The firebox had been stayed throughout with the same material and it is still in use. I have tested one of these sixteen-year-old stays with the following result:—

Breaking load	21·8 tons per square inch.
Elongation on 2 inches	75·0 per cent.
Reduction of area	70·0 „

Stay rod of approximately the same composition made in November 1912 gave:—

Breaking load	23·7 tons per square inch.
Elongation on 2 inches	67·0 per cent.
Reduction of area	72·5 „

That no embrittling of the material has taken place is evident beyond any possibility of doubt, yet these stays have been for sixteen years under the most trying conditions it is possible to conceive. They have been subjected to ever varying temperatures and to constant vibration and racking stresses, which could not fail to produce brittleness if it were possible for it to occur.

I have also investigated these stays under the microscope, with the results shown in the photomicrographs. Figs. 1 and 2, Plate I., correspond to the tests given above. There is prac-

tically nothing to choose between them. Figs. 3 and 4, Plate I., are selected areas of the same at a very much higher magnification. Again there is practically no difference between them. The dark part is a beta area and the light alpha. The slight granulation of the beta is an etching effect. In Fig. 5, Plate II., are shown, by the dark areas, the "cores" in an ingot of this metal recently made up. In Fig. 6, Plate II., will be seen in the same manner the "cores" in the sixteen-year old stay. That they are smaller and more broken up is of course due to the rolling and annealing in the production of the rod.

No one having considered these tests and photomicrographs could possibly doubt that the metal had not changed one iota during the sixteen years from what it was when it was first put into the firebox. Other stays of similar material which have been in use from nine to thirteen years have been examined with identical results. I had not the head of the stay just referred to, but in the case of some similar stays which had been in a firebox twelve years, I have examined both the part of a stay which is in the water space and also the head which had been exposed to the fire. The cores show strongly in each and to the same extent.

Fig. 5, Plate II., has a further interest for us, as it serves as a practical illustration to a useful paper to be read tomorrow by Mr. Gulliver. The cores are due to the first metal to solidify being richer in copper and so on in a diminishing degree as the crystals form. In the micrographs the cores are shown by the formation of a patina during the etching. Each core has probably originated from many centres with gradual shading off. It is, however, difficult to produce a photograph exactly representing that condition; the cores are apt to show equally dark all over. I am indebted to Mr. Licence for the care he has bestowed on the photomicrographs, which had to be produced at very short notice.

The fact that in the sixteen-year old stay the cores show strongly indicates conclusively that little or no diffusion can have taken place in the alloy during that time. It further shows that in the rolling down to rod the metal had not been unduly heated. I would add that the cores in Fig. 5, on

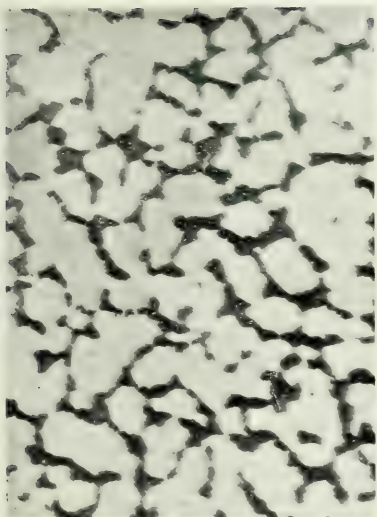


FIG. 1.—Stay in use in Locomotive Firebox
Sixteen Years.
Magnified 127 diameters.

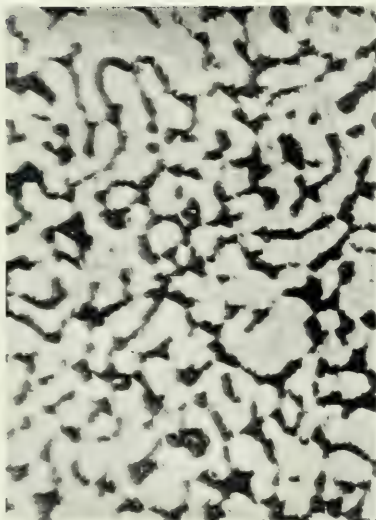


FIG. 2.—Similar Stay Metal Rod,
made November 1912.
Magnified 127 diameters.

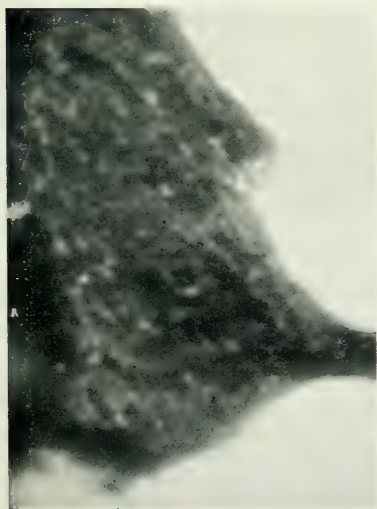


FIG. 3.—The same as Fig. 1.
Magnified 1500 diameters.

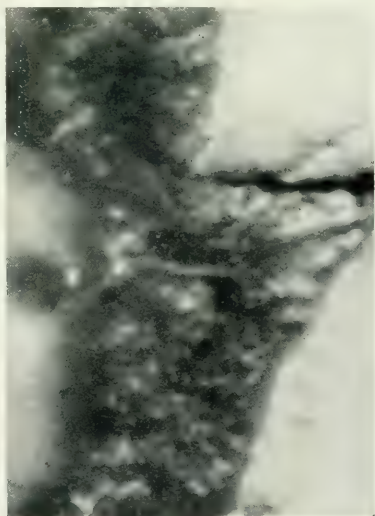


FIG. 4.—The same as Fig. 2.
Magnified 1500 diameters.

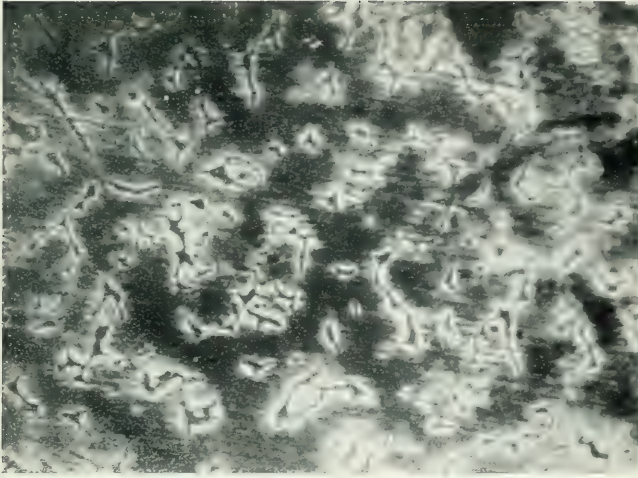


FIG. 5. —Original Ingot of Stay Metal made in November 1912.
Magnified 48 diameters.

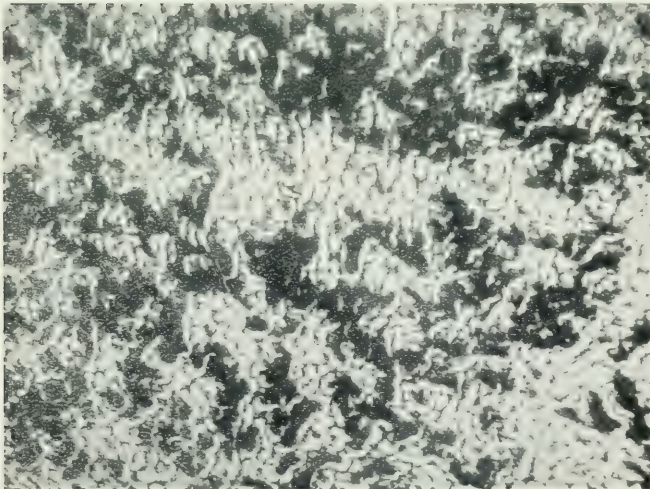


FIG. 6. —Stay in use in Locomotive Firebox Sixteen Years.
Magnified 48 diameters.

examination, will be seen to follow the boundaries of the alpha areas; to be more correct, the boundaries follow the cores. In Fig. 6 it will be seen that the original cored areas have been traversed by beta crystals as a result of the rolling and annealing operations, without, however, the relation of the cores to the original boundaries having been disturbed. There has been no diffusion or recrystallization as we usually understand it. The subject of "cores" is worthy of further investigation by the Institute, I therefore hope that the paper to be read to-morrow will result in a useful discussion.

In concluding, I should like to express my appreciation of the services rendered to the Institute by its secretary, Mr. Shaw Scott. No matter what the services of others, and in many cases they have been considerable, this Institute could not have attained the success it has had if it had not been for the good work of its secretary. Mr. Shaw Scott has been *suaviter in modo, fortiter in re*. These attributes augur well for happiness in the married life into which he is about to enter with the charming daughter of our indefatigable treasurer, and new vice-president, Professor Turner. Miss Turner, who has studied metallurgy and achieved success in the University of Birmingham, will have that sympathy with her husband in his work which is so very helpful. All happiness and success to them in the years to come.

On this happy note I will conclude my address. During my year of office it will be my earnest endeavour to promote the interests of the Institute in every way in my power, but I can only achieve success if I have the sympathy and hearty collaboration of all three sections of the Institute.

METAL FILAMENT LAMPS.*

BY ALEXANDER SIEMENS, M.INST.C.E.

DR. M. V. PIRANI published in *Helios* (No. 46, 1912) an article on the development of modern glow-lamps, which starts by repeating the fundamental necessity of every technical development being guided by the requirements of the consumer.

Foremost among these is economy in the true sense of the word; that is—low first cost combined with low cost of maintenance.

In the case of glow-lamps this means low first cost, long life, and a small consumption of current; but, in addition, such a lamp should be adaptable to existing electrical conditions (varying voltages) and to existing local conditions, which determine its shape and size, and, lastly, that it should not be too sensitive to rough treatment.

All these requirements, except one, are fulfilled by the carbon filament lamp; but its high consumption of current (3·5 watts per candle) at one time endangered the superiority of electric illumination over gas lighting, which, stimulated by competition, had become so economic that the extension of electric lighting was visibly checked.

Curiously enough, the same man whose invention of the “mantle” converted gas into such a formidable competitor of electricity, was the first to manufacture a glow-lamp with an osmium filament using only half the watts per candle, compared with the carbon filament lamp.

Unfortunately, this first metal filament fell short of the carbon filament in other respects: it was exceedingly brittle, it became soft at a comparatively low temperature, so that a lamp with horseshoe filaments could only be used in a vertical position with the filaments hanging downwards, because they could not be stayed in any other position, as they shortened perceptibly when heated. Finally, it could only be manufactured for low voltages.

* Read at Annual General Meeting, London, March 12, 1913.

The further development of the osmium lamp was interrupted by the appearance of the "Nernst" lamp, invented by Professor Nernst of Göttingen.

By employing a conductor of the second class he succeeded in producing light by means of short, comparatively thick, rods capable of supporting themselves and as economical in current as the osmium lamps, although the loss of heat by conduction is considerable owing to the rods glowing in air.

But there are drawbacks, the principal one being that the cold filament does not conduct electricity, so that some special provision has to be made in each lamp to heat up its

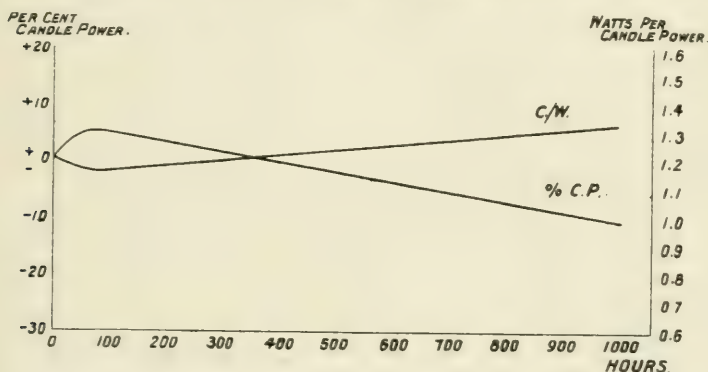


FIG. 1.—Alteration of Candle-power and of Watts per candle with time.
Wotan Lamps of 10 candle-power. 110 volts.

filament; another drawback is the property of the filament that its resistance rapidly decreases with increase of temperature.

On this account it is necessary to insert a resistance in series with each lamp to guard against the effect of variations of voltage.

A decided step forward was the introduction of the tantalum lamp announced by Dr. W. von Bolton and Dr. O. Feuerlein in the *Elektrotechnische Verein* (Berlin), 17th January 1905—E.T.Z., Heft 4, 1905.

They described the research work which had been carried on in the laboratory of the glow-lamp works of Siemens and Halske in Charlottenburg to discover methods for producing

the rare metals in a commercially possible manner, and then to try one after the other as filaments of glow-lamps.

Beginning with vanadium and niobium, Dr. von Bolton found their melting point too low for obtaining results superior to carbon filaments.

In these cases he had followed the same method of working that Dr. Auer had adopted for the production of osmium: the metallic oxide had been mixed with a suitable reducing agent, squirted into thread-form, and heated in a high vacuum.

Proceeding to experimenting with tantalum in the same

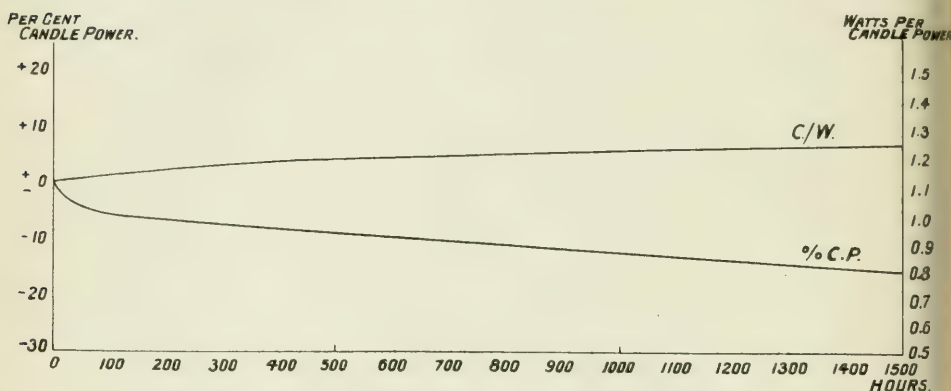


FIG. 2.—Alteration of Candle-power and of Watts per candle with time. Wotan Lamps of 50 candle-power. 220 volts.

manner, he obtained a minute globule of metallic tantalum which proved to be tough and malleable. Thereupon he melted metallic tantalum powder, produced by the methods of Berzelius and Rose *in vacuo*, and obtained pure metallic tantalum which can be hammered and drawn into wire suitable for filaments.

As tantalum has a very much lower specific resistance than carbon, the filaments of tantalum lamps, at equal voltage and equal candle-power, have to be two and a half times the length and one quarter the diameter of equivalent carbon filaments; *e.g.* at 110 volts and 25 candle-power the length of a tantalum filament is 645 millimetres and its diameter 0.047 millimetre against a carbon filament 250 millimetres

long and 0.18 millimetre diameter. Moreover, the softening of the wire at the working temperature made it impossible to imitate the double or treble loop of a carbon filament.

After a good many trials, a satisfactory solution of this problem was found by winding the filament zigzag fashion between two star-shaped supports. In this way detrimental alterations in the position of metallic filaments are successfully prevented.

Further data about tantalum will be found in a Friday-evening discourse delivered by the author at the Royal

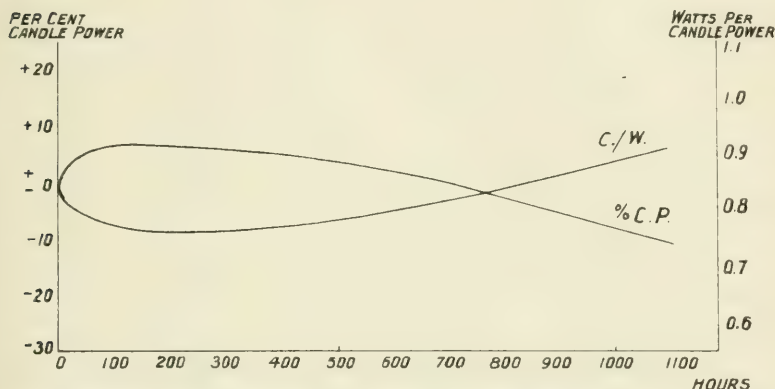


FIG. 3.—Alteration of Candle-power and of Watts per candle with time. Wotan Lamps of 1000 candle-power, 110 volts, (0.85 W. P./C.)

Institution on 23rd April 1909, and about the history of metal filament lamps in three articles of *The Engineer* in December 1906.

As the tantalum filament had all the good qualities of the carbon filament, but consumed only about half the current for the production of the same illumination, it found a ready application everywhere, 103 million tantalum lamps being put on the market during the seven years since January 1905.

Even this great success did not stop the endeavours to utilize metals with even higher melting points than tantalum. One of these is tungsten, melting at about 3000° C., but it was generally known to be too brittle to be drawn into wire. To overcome this difficulty, Just and Hanaman heated

a carbon filament in an atmosphere of chloride of tungsten whereby it was covered by metallic tungsten. Afterwards the carbon foundation was removed by heating in the presence of hydrogen.

Auer produced tungsten filament lamps, calling them osram lamps, by mixing metallic powder with organic materials to a

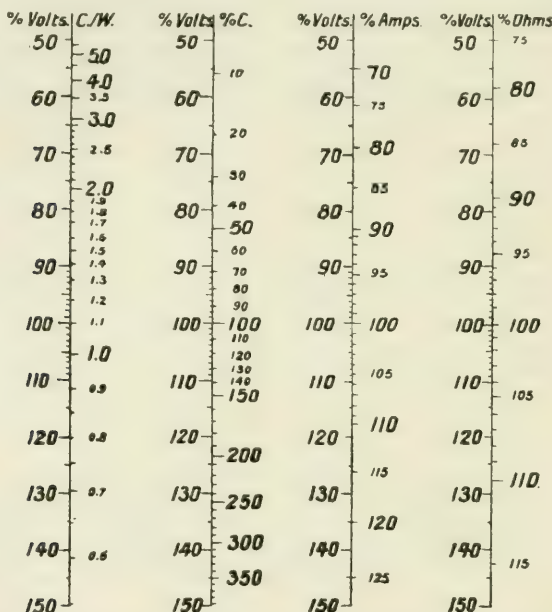


FIG. 4.—Table showing dependence of C/W (Watts per candle) ; per cent. of Candle-power, per cent. of Resistance (Ohms) on the difference of potential in per cent. . . . in Wotan Lamps (100 per cent. = 1.1 Watts per candle).

paste which could be squirted into threads, the additions being removed by heating in hydrogen.

A third method was proposed by Kuzel of Baden, near Vienna, who converted metallic tungsten into the colloidal state and then squirted it into threads which were treated as stated above.

Differing from these squirting methods was a process employed by Siemens and Halske, who mixed metallic powder of tungsten with at first about 10 per cent. (later on 2–3 per

cent.) of nickel, and pressed the mixture into the shape of rods which were heated in an atmosphere of hydrogen up to near the melting point of nickel. These rods were malleable, and could be drawn down to serve as lamp filaments, and their strength exceeded that of the tantalum filament.

These filaments when heated expelled the nickel which would have blackened their globes. They had, therefore, to be heated in special containers until they had lost all their nickel before being placed in the usual globes. It was found, however, that their life was quite uncertain.

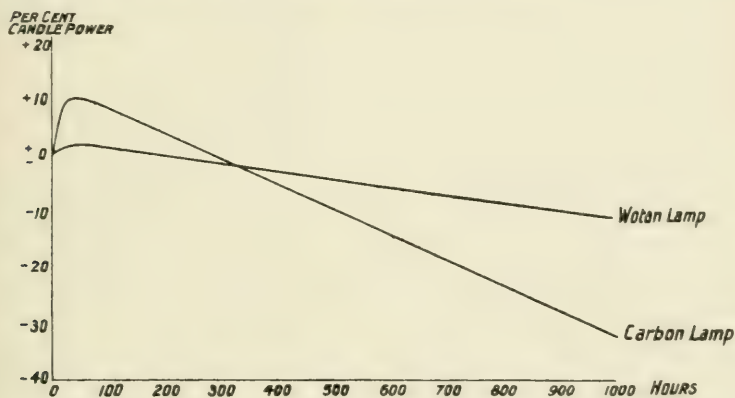


FIG. 5.—Alteration of Candle-power—Wotan Lamps, starting with 1.1 W. P. C., and Carbon Lamps, starting with 3.5 W. P. C.—with time.

While the process was being improved, a decisive step forward was introduced by the General Electric Company (U.S.A.), who patented in 1909 a process for making ductile tungsten, which is described in the British patents 23499/09 and 8031/10, and of which the following is the fundamental fact on which the change in the properties of tungsten is based, viz.: that "by repeated mechanical working, the tungsten being heated during the earlier stage of the operations, a condition is reached where the metal acquires such physical or molecular characteristics that further working may, if desired, be continued at room temperatures."

A very full description of the process will be found in the

Zeitschrift für angewandte Chemie, vol. xxv. Heft 37 (13th September 1912), in an article on the production of ductile tungsten by Otto Ruff.

He first describes the chemical processes necessary for the production of pure metallic tungsten powder.

This is pressed into rods 13 centimetres long and 4 square millimetres in section by a pressure of about 5000 kilogrammes per square centimetre (equal to about 32 tons per square inch).

In order to consolidate these rods, they are at first heated in an atmosphere of hydrogen to about 1300°C ., and afterwards, by passing an electric current through them, to a white heat until the rod is firm enough to be hammered in a swaging machine.

The treatment of heating the rod and passing it through a swaging machine is repeated until the dimensions are sufficiently reduced to commence rolling and drawing through diamond dies in the same manner as other metal wire are treated.

Mr. Ruff concludes his article by saying that the finished tungsten wire is silver white and possesses a very high breaking strain, attaining up to 420–460 kilogrammes per square millimetre (266–292 tons per square inch); it is ductile, tough, very elastic, and non-magnetic. In the air, at ordinary temperatures, it does not change, but it oxidizes on the surface when heated to redness. Pure hydrochloric acid, nitric acid, or fluoric acid hardly attack it, perhaps on account of the formation of a film of oxide, but it is dissolved slowly by a mixture of hydrochloric and nitric acids, and very quickly by a mixture of strong fluoric acid and nitric acid. Undiluted sulphuric acid attacks it only at high temperatures; for instance, Ruder reports* that at 200°C . only 1.1 per cent. was dissolved in eight hours.

Tungsten wire is not attacked by hydrated alkalis, but is oxidized by molten alkalies such as nitrite of potash, or nitrate of potash and chlorate of potash.

Returning to the article in *Helios* written by Dr. M. v. Pirani, he tells us that the Wotan lamps, having pure tungsten filaments, are made in sizes varying from the 5-candle lamp at 110 volts, with a filament 0.01 millimetre

* *Journal of the American Chemical Society*, 1912, vol. xxxiv. p. 387.

in diameter and 330 millimetres long, to the 2000-candle lamp at 220 volts (having an efficiency of 0·85 watt per candle), with a filament 0·275 millimetre in diameter and 2·600 metres long.

A special kind of lamp, for projector purposes, is made by rolling tungsten wire into tape which radiates light at the rate of 1·65 candles per square millimetre surface at an efficiency of 0·75 watt per candle.

The alterations in candle-power and watts per candle while the lamps are burning 1000 hours are shown by the curves on pages 4, 5, and 6, viz. :—

Fig. 1.	10-candle lamp at 110 volts	} Starting with 1·1 watt per candle. 0·85 „ „
„ 2.	50-candle lamp at 220	
„ 3.	1000-candle lamp at 110	

A table (Fig. 4) shows the variation of watts per candle amperes and resistance depending on the variation of volts (100—normal).

The last curve (Fig. 5) shows the variation of the illuminating power in a Wotan lamp starting with 1·1 watts per candle and in a carbon filament lamp starting with 3·5 watts per candle.

These results, taken together with the high temperature at which the tungsten lamp works, make it very doubtful whether it will be possible to construct a much more economical glow-lamp, so that the consumer will have to look for further economy to the improvement and cheapening of the electric supply.

DISCUSSION.

MR. ALEXANDER SIEMENS, in introducing his paper, said that the printed paper contained a summary of the history of metal filament lamps. People made endeavours to make glow lamps with metal filaments in the early forties, but at that time neither the supply of electricity, nor the apparatus for creating the vacuum, nor many other details, were in such a state as to enable them to attain successful results. The metal filament was taken up by Edison, who tried platinum, but it was not satisfactory, on account of its low melting point. Then the carbon filament came in, which really fulfilled all the requirements which could be asked of a glow lamp, except that it took too much current. Endeavours had therefore never ceased to produce a filament which could stand a higher temperature than carbon (carbon

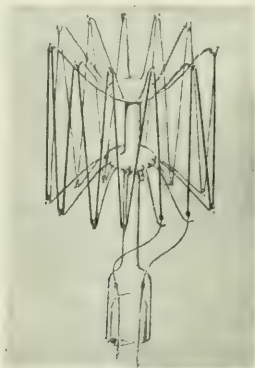


FIG. 1.—“Spider” wound with Tantalum Wire Filament.

did not melt, but it disintegrated at high temperatures), and thereby give more economical results, and convert more of the energy into light. He desired to show one experiment to demonstrate that point. The members would notice on the table two glass jars. In one of those glass jars he had put a carbon filament lamp, while in the other he had placed a metal filament lamp. He proposed to have the jars filled with water; to put in two thermometers and take a reading; then to turn the current on and watch the result. Both lamps were supposed to be 25 candle-power at 200 volts. They therefore ought to give the same light, but the carbon lamp consumed very much more energy, as would be shown by the fact that the water in which the carbon lamp was placed went to a higher temperature very much quicker than the one in which the metal filament lamp was.

The experiment was then carried out, and Mr. Siemens subsequently announced that the water in which the carbon filament lamp was immersed showed a temperature of 95° , while the water in which the

metal filament lamp was immersed showed a temperature of 68° , the water in the first instance, before the lamps were put in, being 58° . The first successful metal filament lamp, Mr. Siemens said, was made by Mr. Auer, who made a paste of osmium mixed with deoxidizing agents, which he squirted into a sort of filament, which was afterwards heated in an atmosphere of hydrogen, and subsequently *in vacuo*, so as to convert the metallic oxide into metal. He was so far successful that he produced a lamp which, instead of using $3\frac{1}{2}$ watts per candle-power, used only about 1.7. But the filaments so obtained were very brittle, and could hardly be used in any position without a special fastening. That led to investigations being extended to other metals. Most people

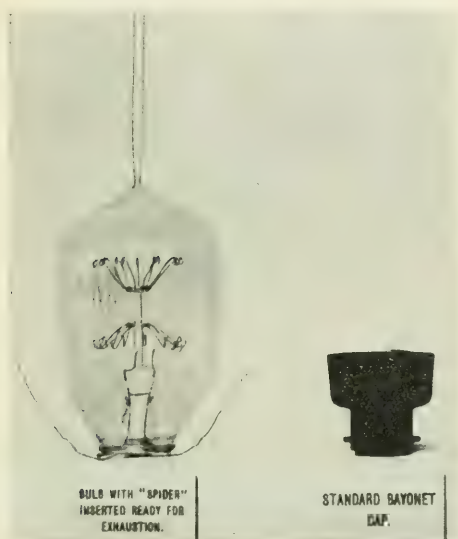


FIG. 2.

tried the Auer method, but progress was made by Siemens and Halske's discovery of how to make metallic tantalum, which proved to be so ductile that it could be drawn through diamond dies into fine filaments, which took about as much current as the osram or osmium lamps, but which were infinitely stronger. He gave a lecture on tantalum and its applications before the Royal Institution, and he would not repeat what he said on that occasion. Siemens and Halske went on experimenting in their lamp works, which were managed by Mr. Feuerlein, who, with the late Dr. Bolton, first described the tantalum lamps, and in their research laboratories, presided over by Dr. Pirani. Dr. Pirani succeeded in producing an alloy of tungsten and nickel. At first he used 10 per cent. nickel, but gradually the mixture went down to 2 and 3 per cent. The lamp was in a way very successful, but the result was uncertain.

While further experiments were still being made to overcome those difficulties, the General Electric Company in America succeeded in

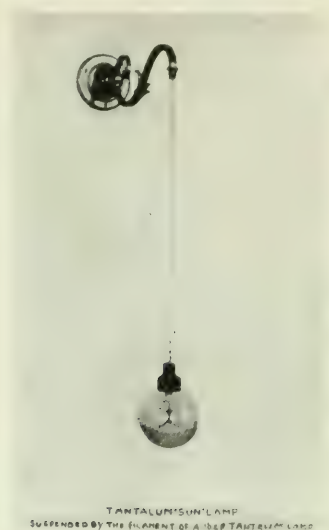


FIG. 3.

converting the brittle tungsten into a ductile metal by simply working it, heating it in an atmosphere of hydrogen, then hammering it carefully

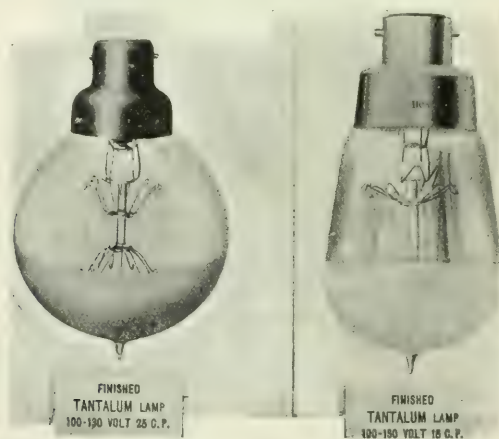


FIG. 4.

in a so-called swaging machine, and repeating that until the rods could be drawn out into wire. That had been found very successful—so

successful that the wire had been drawn out to a very small diameter. He desired to show the members a series of slides illustrating the manufacture of the lamp, and he also had with him some samples which



FIG. 5.

he would hand round for inspection. Before doing this he wished to describe the production of metallic tungsten, which consisted, in the first place, of the ore being converted into oxide, which was afterwards reduced so that the tungsten metal was obtained in the shape of powder.



FIG. 6.

That powder was compressed in a hydraulic press into the shape of a rod, but the rod was so fragile that it had to be left at first on its support. It was then put into a porcelain tube, which was heated from the outside, a current of hydrogen going through to prevent oxidation ;

then it was hammered as he had previously stated, and was eventually drawn out to a very fine wire. He desired to show to the members a specimen of the finest drawn tungsten wire, which was 0.015 millimetre in diameter—the $\frac{1}{66}$ th part of a millimetre. [In order to illustrate the transformation which was produced by the working, two slides were then thrown on the screen. Other slides were also projected, including Figs. 1-6.—ED.]

He now proposed to show an experiment with a filament, which was $\frac{1}{20}$ millimetre in diameter, in order to show how strong it was. He would attach a weight of 500 grammes, a little over 1 lb., to that filament, and it would be seen that the wire held it quite comfortably. The strength of the tungsten was very extraordinary; it increased as the wire was drawn finer. Wire which was $\frac{1}{10}$ millimetre in diameter had a strength of 27,000 kilogrammes per square centimetre, which corresponded to 180 tons per square inch. If it was drawn finer down to $\frac{1}{66}$ th part of a millimetre, *i.e.* 0.015, then the strength was 57,500 kilogrammes per square centimetre, corresponding to 380 tons per square inch.

All metallic filaments possessed the quality that with increasing temperature their resistance increased, and that enabled them to stand a much heavier overload than other lamps. The members would notice that a stand was exhibited containing a number of lamps. Those lamps were 110 volts. He proposed to ask his assistant to take out resistances until the full current which was available in the Institution was put on the lamps, namely, 200 volts. [The current was switched on, and all the lamps stood the overload.]

He also proposed to show the members that metallic filament lamps could stand shocks. He had an 8 oz. ball, which he proposed to allow to run down the slope that had been prepared on the table, and hit up against a lamp, first, when it was not burning, and secondly, when it was burning. [The ball was allowed to run down the slope.] It would be seen that it made no difference to the lamp, and did not break the filament. He also had another apparatus, which was rather a plaything, to show what the lamps could stand in the way of movement. [A lamp was subjected to severe movement in the apparatus referred to.]

Professor A. K. HUNTINGTON, Assoc.R.S.M. (President), said that he was sure all the members were very much obliged to the author for giving such a delightful little lecture. It made the subject so very much more interesting to have it illustrated in the way he had done. Listening to the paper carried his mind back thirty years, which, however, seemed to him almost like the previous day when he recollected what was being done at the time. It was the time that Sir William Siemens introduced the first electric furnace, which was shown at the Smoke Exhibition, and he persuaded the late Sir William Siemens in a weak moment to let him (the President) have the furnace at King's College: he did not think the author was on watch at the time. The furnace remained at King's College for some months. It was a rather costly installation, there being five dynamos of the D 2 type, one exciting

the other four. He was allowed to play with that delightful piece of apparatus, greatly to his joy as might be imagined. Amongst other things he tried melting tungsten, but he found he was up against a proposition very much tougher than he appreciated when he started the experiment. He found that its volatilizing point was very near its melting point, and that the great power of the arc playing on a small area volatilized the metal there without melting the rest. It was only after a great struggle that he succeeded in getting a solid piece of tungsten by building up little by little. Up to that time the tungsten had only been obtained in powder. He succeeded in getting pieces as big as the top of the thumb which contained a certain amount of carbon—if he remembered rightly about 1 per cent.—and they were shown at the British Association Meeting in 1884 at the reading of the joint paper by Sir William Siemens and himself. Getting that tungsten led him to think that tungsten would be a very fine substitute for carbon, inasmuch as so much current would not be required. At that time Mr. Ferranti was with Sir William Siemens, and was in charge of the apparatus. They filled up a long churchwarden pipe stem with powder and compressed it as best he could; he forgot whether any material was used to stick it together, but he did not think it was. Then the current was turned on. It was not a very ideal way of trying it, but it was only a first step. The substance gave out a very powerful light, and eventually the current was turned on to such an extent that the whole thing blew up. It was not thought desirable, for one reason or another, to go on with the matter; it was before its time, he supposed, and the idea was not followed up. He could not help thinking that if it had been followed up, tungsten lamps might have been in existence years and years ago, with considerable advantage to electric lighting. However, it was no good crying over spilt milk, although it made his mouth water to look at the beautiful examples exhibited that morning and think of what happened thirty years ago. He did not know whether the author remembered it, but personally he had not forgotten it. With regard to the question of the strength of the material, it was a great pleasure to him to see the tungsten come out as it had, because he had always held that if a metal was malleable in alloy with other metals it was malleable itself. He might be wrong, but it had always been in his mind that that was actually a fact. The converse of that did not of course hold good. A metal might be brittle in an alloy, and yet might be malleable in itself, because compounds might be formed which were brittle although the components of the metal were not themselves brittle. In conclusion, there were one or two questions he would like to ask. With regard to the strength of the tungsten wire, he would like to know how it compared with steel when drawn down to the same diameter, because it was well known that the finer metal was drawn down, the greater the strength. With regard to the process for producing tungsten wire, the members had been told that alternate heating, hammering, and swaging were used. He desired to know whether that was the reason for the effect stated, or whether it was the withdrawal of

the carbon by the presence of hydrogen which led to the ultimate malleability of the tungsten being worked on.

MR. ARNOLD PHILIP, B.Sc. (Member of Council), said the preparation of tungsten was so novel that practically all one who had not had an opportunity of preparing it and experimenting with it could do was to ask questions. He did not think any information was contained in the literature he had seen on the subject which dealt with the physical properties of tungsten. No doubt the manufacturers of the wonderful material Mr. Siemens had described were in a position to state its specific gravity and its resistivity. Its melting point must be so high that its determination must involve great difficulties; he would like to know if it had been possible to determine it. Personally he was accustomed to think of the diameters of the wires not in terms of millimetres but in terms of thousandths of an inch. He had just jotted down the figure which Mr. Siemens stated as the diameter of the wire which had a strength of 380 tons per square inch, namely 0.015 millimetres, and found that this was equivalent to a little more than half a thousandth of an inch.

MR. SIEMENS said it was one-sixtieth of a millimetre.

MR. ARNOLD PHILIP agreed with Mr. Siemens. Half a thousandth of an inch was a very fine fibre, the toughness of such a fine tungsten wire was quite extraordinary. He had been interested to hear the President ask the question as to what was the ultimate tensile strength of steel wire drawn down as fine as that. He fancied plough steel wire ran to about 130 tons, but that would be in the form of a comparatively thick wire, and if it were drawn down to very fine diameters it would no doubt be considerably higher. But he thought it was improbable that steel wire had ever been drawn down as fine as half a thousandth of an inch.

MR. W. H. JOHNSON, B.Sc. (Vice-President), thought the paper presented many points of interest in regard to the use of the rarer metals, by which he meant metals that were uncommon and were only just beginning to be used, such as tungsten and tantalum. He took great interest in the figures which the author had quoted as to the wonderful breaking strain of tungsten.

MR. G. A. BOEDDICKER (Member of Council) said that two points interested him specially in the paper, the first being that the production of a homogeneous ductile metal from a refractory powder simply by pressure was the only instance with which he was acquainted. Another point had interested him greatly, on which he hoped the author would give further information, namely, how the metal was annealed during the process of drawing it down to such a fine size.

MR. E. L. RHEAD, M.Sc. Tech. (Manchester), said that if the President's views that metals which were malleable in their alloys would themselves be

malleable if properly treated were correct, it should be possible to obtain malleable antimony and bismuth, since an alloy of antimony and tin containing more than 10 per cent. of the former metal could be rolled with ease. In the case of tungsten enormous changes had been induced by the mechanical treatment to which it had been subjected, but the probability of obtaining similar results with antimony and bismuth was much more remote, as the two metals in question had been known and experimented with for so long. The field for research in that direction was much less promising. Another point that might be further remarked upon was the facility with which tungsten took up carbon at high temperatures. In early attempts at reduction he had been unable to obtain the metal with less than about 10 per cent. carbon. The brittleness was attributed to the presence of that element. He further asked whether the carbon deposit formed by the process of "flashing" on the older type of squirted filament had any effect on its strength and durability.

Mr. J. P. BEDSON (Manchester) said that as a steel wire drawer 380 tons per square inch breaking strain struck him as being very marvellous, and he would very much like to be let into the secret that would enable him to make steel which would give anything like half that amount with safety and durability. Steel was capable of being drawn down to very small sizes, but when one got into the neighbourhood of 30 it was very difficult work indeed. Although he knew of steel in fine sizes giving 150 to 180 tons breaking strain per square inch, still the drawing of the wire to that weight impoverished the material. The question that he particularly desired to ask the author in relation to the wire was whether it would stand any bending at that high strain of 380 tons or whether it was brittle at that point. He did not know whether he was right in assuming that the tungsten wire should be annealed again before it was applied to the lamp and bent round. High-strained steel wire which was to be used for pianos in the finer qualities of wire, had to stand a bending test round a peg. All high class wire had to stand a test round itself and back again three or four times over, so that the members would appreciate there was a good deal of life left in the wire at 120 tons when it was capable of doing that. It would be of great interest if the author would state what bending the tungsten filament would stand, and whether a pinch of tungsten in a melt of steel would add 50 or 100 tons to the working strain per square inch. If that were the case it would be very valuable to wire-drawers.

Mr. GEORGE HUGHES (Member of Council) said he desired to make only one remark, namely, that, as representing a very large consumer, he thought it only right that he should testify to the excellence and reliability of the author's lamp.

Mr. F. W. WILLCOX (British Thomson-Houston Company) stated, it was very difficult for anyone to do justice to such a large subject as Metal Filament Lamps in a very short paper such as this, and no

doubt this was a difficulty the author had experienced. In such a short paper one necessarily would have to omit many important matters.

The first point to be commented upon was the efficiency value given; this value was evidently based on "Hefner" candle-power and not an English candle-power. It would be very desirable to have the author state if Hefner candle-power values were referred to.

Mr. ALEXANDER SIEMENS said that the figures were based on Hefner candle-power.

Mr. WILLCOX, continuing, said that the Hefner candle-power had a 10 per cent. lower value than the English, so that the efficiency values stated in the paper would, on an English basis, be 10 per cent. poorer values, *i.e.* not so high an efficiency by 10 per cent. Furthermore, in the values given on page 47 it should be noted that the efficiencies which lamps would require to give the life results shown would vary with the voltage and size of lamps. The efficiency of any metal filament lamp was poorer for the higher voltages (200 volts), than it was for the lower (100 volts), and also poorer in general for smaller sizes than for larger sizes.

It was hardly possible to over-emphasize the credit due to Von Welsbach in the development of metal filament lamps. No doubt if the paper had been longer, the author would have been able to have given more emphasis to the important work of Von Welsbach. It was through the latter's work that it became possible to make the tungsten filament a commercial possibility. He was the first to teach the world how to make a coherent filament from metallic powder. His work, however, was confined to the one metal—osmium, which metal he considered the appointed metal for filaments. Von Welsbach gave the process, and it was for others to take advantage of it and apply it to a more practicable metal than osmium. Just and Hanaman were fortunate in making that application. The so-called Just and Hanaman process of manufacturing tungsten filaments was wrongly referred to by the author. The processes used by the licensees under the Just and Hanaman patent were two, one to take the tungsten powder, mix it with an organic binding medium, squirt filaments, baking them to make them conductive, and then pass current through them in an atmosphere of hydrogen and water vapour, the purpose of the hydrogen being to prevent the tungsten from oxidization, and the water vapour to remove the carbon by oxidization, so as to leave a filament of pure tungsten.

In view of the above, it would seem that the author was in error in the statement that Auer produced tungsten filaments, when he really confined himself to osmium. After Just and Hanaman had applied Auer's process to tungsten the manufacturing production of a tungsten filament lamp was taken up by the Auer Co. (D.G.A. of Berlin). The author had omitted to refer to the work of Dr. Coolidge, of U.S.A., on the use of amalgam binders and on the use of alloy metals, which were quite important developments in the application of metallic filaments.

The development of the drawn tungsten wire filament was a most revolutionary development because it was thus made possible to correct the one deficiency of tungsten lamps by making the lamp durable and comparable in strength with ordinary carbon filament lamps. The production of the tungsten lamp was made a much more definite process as the result of using a continuous filament which could be wound in an unbroken length on its supports, in place of the previous sectional filament which had to be spliced and held together at various points.

Mr. EDWARD J. BOLTON (Oakamoor) said it was not quite clear to him from the author's remarks how it was possible to swage a bar of tungsten small enough to draw it through a diamond die without any intermediate process, such as rolling or something of that sort.

Mr. ALEXANDER SIEMENS remarked that rolling was done; he omitted to mention it.

Mr. ALEXANDER SIEMENS, in reply, said he thought Mr. Willcox had not appreciated all he had said in his paper of Dr. Auer von Welsbach. Welsbach and Auer were one and the same man. He had given references to some other papers because he did not wish to burden his present paper with details, and the work of Dr. Auer von Welsbach was fully appreciated there. In those papers the process which Dr. Coolidge had proposed (also squirting lamp) was mentioned, but he did not think it was worth while to spend much time in referring to squirted lamps, because that stage in the manufacture of metal filament lamps had been passed, and nobody would dream of making them now. Mr. Bedson wanted to get a steel with half as high breaking strain as that of a tungsten filament. He desired again to refer to the fact that the 380-ton material was a very fine one. When the filament was $\frac{1}{16}$ millimetre diameter the strength was 180 tons per square inch, which, as has been said, was also that of very thin steel wire. If still thicker material was used, of course, the breaking strain diminished, but anyhow it seemed stronger than steel.

Mr. Boeddicker was astonished that homogeneous metal could be produced by pressure. It was not strictly pressure alone. The coherence of the little rod when it left the hydraulic press was very small indeed; it could very easily be disturbed and made to fall to pieces again. That was put into a porcelain tube and heated while hydrogen was passed through the tube. Then it seemed to get a little more strength; it was then heated again in a current of hydrogen, and an electric current was passed through it to make the particles adhere to each other still more. Eventually it was passed through a swaging machine which just touched it: it did not do much to it. Between each pass through the swaging machine and the next it was put again into a porcelain tube through which hydrogen went, and it was heated. After it had been passed through the swaging machine and through rolls, it was not necessary to heat it any further, although it was very often done. There was perhaps a little less mechanical power necessary to

draw it down, but it was perfectly ductile while it was cold, and it did not want any annealing at all in the sense that steel was annealed; it did not get hard. The diameter of the wires was calculated from the length and the weight. The wire exhibited was $\frac{1}{16}$ millimetre in diameter and had a 500 gramme weight on it. The wire could be bent; as a matter of fact it had been wound round in order to fasten the weight on to it, and also at the top as well, so that it seemed to be absolutely elastic. With regard to the physical properties of the tungsten, he had quoted in his paper what Mr. Ruff said in his article, "That the finished tungsten wire is silver white and possesses a very high breaking strain, attaining up to 420-460 kilogrammes per square millimetre (266-292 tons per square inch); it is ductile, tough, very elastic, and non-magnetic." That was the information Mr. Philip asked for. The President asked whether the withdrawal of carbon was the cause of the ductility. The powder was prepared from the dioxide W_2O_3 , and was absolutely pure. Very great care was taken during the reduction not to bring any carbon anywhere near it, so that the powder which was eventually compressed was absolutely pure tungsten. It was very necessary to make it as pure as it could be possibly obtained in order that it should adhere a little bit. If, however, any carbon got into it it was taken out by the hydrogen which was passed over it. He had already stated that the steel, according to Mr. Bedson, was really quite as strong as tungsten, and he desired to remind the members in addition that tungsten had been used as an alloy of steel, and that the alloy was exceedingly strong.

COMMUNICATIONS.

Professor A. K. HUNTINGTON, Assoc.R.S.M. (President), wrote, with reference to Mr. Rhead's remark regarding tin and antimony, pointing out that in an alloy of tin with 10 per cent. of antimony a hard, brittle tin-antimony compound in cubical crystals of the approximate composition $SbSn$ was formed, which remained in suspension in the excess tin. It was a condition which existed in many white bearing metals. Those crystals would separate from the excess tin if the mixture were kept molten and undisturbed for a sufficient time at a low temperature. If such a mixture could be rolled it was due to the great softness of the excess tin, and it in no way disproved what he (Professor Huntington) had said.

Mr. E. L. RHEAD, M.Sc.Tech. (Manchester), wrote, that he would like to ask the author whether filaments of drawn wire were as suitable for alternating as direct currents, or whether a change took place that rendered them brittle and thus reversed the effect of the mechanical treatment?

Mr. SIEMENS, in reply to Mr. Rhead, wrote that drawn tungsten filaments were as suitable for alternating as for direct currents.

CONTRIBUTIONS TO THE HISTORY OF CORROSION.*

PART II.

THE CORROSION OF DISTILLING CONDENSER TUBES.

By ARNOLD PHILIP, B.Sc., A.M.I.E.E., Assoc.R.S.M.
(ADMIRALTY CHEMIST).

DISTILLING apparatus is largely used both on merchant steamers and on ships of the Royal Navy for the purpose of preparing fresh water, not only for washing and cooking purposes, but also for supplying the make-up feed water for the steam boilers.

The distilling apparatus consists in general of two parts. Firstly, a cylindrical boiler or evaporator which is fed with sea water either by hand or automatically. In this sea water a steam heating coil is either partially or totally immersed. Through this steam heating coil a current of high-pressure boiler steam (primary steam) is passed at a temperature of from 240 to nearly 400° F.

The raising of the sea water surrounding the coils to this temperature causes it to boil, and the steam (known as secondary steam) which is thus evolved from it passes over into the second part of the distilling plant. This is known as the distilling condenser, and is in general very similar in construction to the forms of main and auxiliary condensers used on steamships.

There are, however, one or two differences between the construction of the distilling condenser and the auxiliary and main condensers as now generally used in H.M. service which should be noted. In the distilling condenser the steam passes through the condenser tubes and the cooling water circulates outside them. This is the reverse of the usual practice in main and auxiliary condensers. Secondly, the tubes in the distilling condenser are usually vertical and expanded into the

* Read at Annual General Meeting, London, March 12, 1913.

tube plates, whilst in the main and auxiliary condensers they are horizontal and pass through watertight glands in the tube plates.*

It is interesting to remark here that, whether on account of the fact that the distilling condenser tubes are vertical, or whether because they are expanded at their ends into metallic contact with the tube plates, or whether because the sea water circulates outside the tubes inside a steel casing instead of inside the tubes, no case is known to the author of corrosion trouble occurring to the tubes in these condensers on their sea-water side. This statement that corrosion is absent on the sea-water side of condenser tubes in a distilling condenser merely represents the author's personal experience and the results of the inquiries he has been able to make, and to this extent it appears to confirm the views already expressed by him in previous communications to the effect that by far the greater part of the trouble with the corrosion of condenser tubes with sea water is due to the presence of carbon or other electrically conducting relatively electro-negative body deposited along the inside of the tubes at the bottom, and that on the other hand practically all the other less important corrosive actions can be stopped by the use of masses of properly connected iron and steel or perhaps aluminium and zinc as protective metals.

Notwithstanding this freedom from corrosion of the tubes of distilling condensers upon their outer or sea-water surfaces, very great difficulties have been experienced from the corrosion of these tubes upon their inner or steam surfaces.

From time to time in the past, what in the aggregate is a large number of cases have occurred in which very serious corrosion has taken place on the steam side of the condenser tubes of sea-water distilling apparatus.

The trouble usually first made its appearance by the presence of what was believed to be priming in the distilling evaporator. This was indicated by the fact that the water

* It should be stated that distilling condensers of other patterns in which the cooling water passes through the tubes and also in which the tubes are horizontal are used, but the type most generally employed until recently is that here described, and the remarks as to corrosion on the sea-water side of distilling condenser tubes must be understood to apply to this form of condenser only.

from the distilling condenser gave a precipitate or cloudiness when tested with silver nitrate solution. More marked symptoms of corrosive action were indicated by the distilled water possessing a disagreeably metallic taste, and reports from various ships showed that soap used with such water sometimes gave a light bluish-green curd. In one case the distilled water, after boiling in the ship's "copper," was used for making tea, and gave a black coloured infusion, whilst the ship's "copper" (actually made of iron) became coated internally with metallic copper. In short the distilled water contained copper, and on examining the distilling condenser tubes they were found to be markedly corroded on their steam side. The corrosion was so active that the distilled water in once passing through the tubes dissolved sufficient copper from them to produce the troubles referred to. The cause of the presence of the copper was at first, as stated above, attributed to the priming of the sea water in the evaporators, and the action of the sea salt thus passing over into the distilling condenser tubes was looked upon as causing the solution of the copper. This view appeared to be confirmed by the fact that the usual silver nitrate test of the distilled water seemed always to demonstrate the presence of salt.

Early endeavours to reduce the effects of the supposed priming were made by coating the insides of all the condenser tubes and other steam pipes with tin, whilst steel and zinc vapour baffle plates and protector blocks were placed in the head of the evaporator and in the vapour pipe connecting the head of the evaporator with the distilling condenser. Both these remedies were found to effect a temporary cure, but unfortunately after a while the same troubles reappeared. The degree to which these difficulties, due to the corrosion of the tubes and the presence of copper in the distilled water, were noticed was found to vary a good deal in different ships, and even in the same ship marked fluctuation occurred from time to time.

The author's first examination of a case in which corrosion of distilling condenser tubes had been observed was in August 1904, and on looking through previous correspondence upon this and other similar corrosions he found, in a letter written

by an engineer officer in 1903, the suggestion that as part of the heating surface of the primary steam coils in a particular evaporator was under normal conditions of working left above the sea-water level, it was possible that this getting quickly coated with scale and consequently overheated might evolve hydrochloric acid from the magnesium salts found in the deposit, and that it was the acid thus evolved which caused the corrosion observed in the distilling condensers.

This observation appeared to be a very probable explanation of the corrosive troubles which had been noticed, and steps were at once taken to fully examine the particular case then under question from this point of view.

It was found that generally evaporators may be divided into two classes, namely, those containing drowned heating coils (*i.e.* in which the primary steam coils are completely immersed in the sea water or brine which they are used for heating), and those in which the primary steam coils are only partially covered with water.

Experiments made on board a ship which was fitted with evaporators both of the drowned coil type and the partially exposed coil type showed that when connected to the distilling condenser the drowned coil type evaporator always made water practically quite free from copper, whilst the evaporator with the exposed heating coils when connected to the same condenser gave water which contained copper.

The brine from both types of evaporator was then examined, and it was found that from the drowned coil type it had a very faintly alkaline reaction to phenolphthalein, whilst the brine from the evaporator having the partially exposed heating coil possessed a very strongly alkaline reaction to the same indicator.

On opening up an evaporator and examining the inside surfaces of the walls of its casing, it is usually found that the lower portion, which contains the sea water or brine which is undergoing evaporation, is coated all over with a brilliant white incrustation, and this white incrustation extends upwards above the level of the brine, as far in fact as the water can splash when boiling. Above this region, however, the inside surfaces of the head of the evaporator (if it is not of the drowned coil

variety) are usually much corroded and coloured a deep orange-brown. The tops of the steam coil, as far as they project above the surface of the brine, are also thickly coated with white incrustation. Chemical analysis shows this incrustation to be a mixture of calcium sulphate and basic sulphate and chlorides of magnesia, together with a considerable proportion (2.35 per cent.) of magnesium hydrate. This incrustation is normally heated up to practically the same temperature as that of the primary steam, *i.e.* to a temperature considerably over that of the boiling brine, and it is at the same time constantly splashed with the boiling brine itself. Under these conditions the magnesium chloride present is decomposed, hydrochloric acid is evolved with the steam, and a strongly alkaline incrustation and also an alkaline brine are formed.

The chemical tests on the white incrustation and the alkalinity of the brine itself clearly show that some acid must have been driven off by the process of treating the sea water in the evaporator. Sea water is itself quite neutral to phenolphthalein to commence with, and the amount of alkaline base found to be separated was much greater than could be explained by any other hypothesis than that hydrochloric acid had been driven off.

In order, however, to demonstrate beyond dispute that hydrochloric acid was actually evolved, it was considered desirable to prove its presence in the distilled water.

This was a matter of some little difficulty, on account of the very small amount in which the acid was present, namely, from 0.1 to 0.05 or less parts of HCl per 100,000. To determine the acidity of such a weak solution by direct titration is not a satisfactory procedure. Hydrochloric acid is so volatile that it is not possible to concentrate it by evaporation. The distilled water, besides containing hydrochloric acid, also contains sodium chloride due to slight priming, and also chlorides of copper, tin, and zinc, formed by the acid water flowing through the condenser tubes. The quantities of these metallic chlorides which are present in the water are of about the same order of magnitude as the amount of hydrochloric acid itself. As these salts lose HCl on evaporating to

dryness, the method of determining the difference between the total chlorine present in the water and then the chlorine present in the solid residue after distillation to dryness does not give the correct amount of free hydrochloric acid present.

The method of test which was finally adopted was to add sufficient of a saturated solution of pure sulphate of silver (7.72 grams per litre) to the water. This causes a precipitate of silver chloride to be formed, and free sulphuric acid equivalent to the amount of free hydrochloric acid present is liberated: after heating to coagulate any silver chloride formed, it is filtered off and a large bulk of the water thus treated is evaporated down to a small bulk. This then contains all the free sulphuric acid. To demonstrate that it was free sulphuric acid a portion of it was dropped on a piece of lump sugar, and this was heated for an hour in a water oven at 210° F. The presence of the sulphuric acid was demonstrated by the blackening of the sugar as the acid became concentrated, whilst a similar piece of sugar treated as a control with a residue from ordinary distilled water to which the same amount of the silver sulphate solution had been added gave no blackening. In order to be certain that the silver sulphate was itself quite free from acid before use it was washed by boiling up with successive small quantities of distilled water, and the washed salt was employed for making up the silver sulphate solution used in the experiments. The actual determination of the amount of the free acid present was carried out by a titration on the concentrated residue, obtained from a further portion of the water under examination, after it had been treated with the pure silver sulphate solution as described above.

Tests carried out in this manner showed that the water obtained from distilling plant which caused corrosion of the condenser tubes, and which contained copper, invariably also contained free hydrochloric acid.

The amount of copper present in such waters is conveniently estimated by a colorimetric test, using potassium ferrocyanide in comparison with standard solutions of a copper salt.

The results of some actual tests made upon samples of water obtained from two distilling plants, in which one had an

evaporator with the upper portion of its primary steam coils above the surface of the boiling brine, whilst the other had its steam coils drowned (that is to say, completely immersed beneath the surface of the brine), are here given:—

Type of Evaporator.	Coils exposed above the Surface of the Brine.		Drowned Coils.	
	16 tons	8 tons	13 tons	5 tons
Rate of working evaporator in tons of distilled water per diem . . . }	16 tons	8 tons	13 tons	5 tons
Pressure of primary steam in lbs. per square inch absolute . . . }	215 lbs.	60 lbs.	40 lbs.	25 lbs.
Corresponding temperature of primary steam }	337·4° F.	292·5° F.	267·1° F.	240° F.
Pressure of secondary steam in lbs. per square inch absolute . . . }	30 lbs.	27 lbs.	18 lbs.	15·5 lbs.
Corresponding temperature of second- ary steam }	258° F.	244·1° F.	221·9° F.	214·5° F.
Copper in grains per gallon present in the distilled water obtained . . . }	0·32	0·56	0·005	0·008
Reaction of the brine in evaporating to phenolphthalein }	strongly alkaline	strongly alkaline	very faintly alkaline	very faintly alkaline
Reaction of distilled water to methyl orange }	faintly acid	faintly acid	faintly acid	faintly acid

At the date at which these results were obtained, 1904, the method of determining quantitatively the amount of free hydrochloric acid present had not been worked out, but tests for free hydrochloric acid made upon other samples of distilled water by the silver sulphate method a few months later showed, as has been stated above, that this acid in the free state is always present in the distilled water obtained from an evaporator in which the primary steam coils are exposed in the secondary steam space above the brine.

From the results given above, however, it is apparent that the rate at which an evaporator is worked, or, in other words, the temperature of the primary steam, caused the amount of copper in the distilled water, and therefore of the hydrochloric acid formed in the evaporator, to vary. The more the evaporator is pressed, the greater the amount of hydrochloric acid

formed in a given time. There is further some evidence to show that the evolution of hydrochloric acid from the salts in sea water may not only be caused by the heating of the saline incrustation on the heated steam coils, but that this acid may also, but to a much smaller extent, be given off from the incrustations formed on the lower sides of the evaporator shell, and also possibly even from the brine itself, and in a given form of evaporator the formation of free hydrochloric acid is favoured by the high temperature of the primary steam coils and the strong concentration of the brine. To obtain the least quantity of hydrochloric acid from a given evaporator, it is therefore necessary to avoid too great a concentration of the brine by suitable adjustment of the sea-water feed and brine cocks, and also, and most effectively, to reduce the rate of evaporation as much as possible. Both of these methods of remedying the trouble are, however, faulty, for they both tend to render the evaporator inefficient. The best remedy is to only use evaporators with drowned steam coils.

The passage of copper into the boilers with the feed water is, of course, most undesirable from the point of view of boiler corrosion, and it has been proposed to avoid this by passing the distilled water through a scrubber of large granulated zinc or small zinc blocks. The feed tank into which the water from the distilling condensers is pumped is usually fitted with zinc protectors attached to its walls. In the absence of zinc scrubbers, if owing to defects in the evaporators the presence of copper in feed water is unavoidable, its harmful effects may be best minimized by keeping the water alkaline with lime, for this causes the objectionable soluble copper salt to be converted into the comparatively harmless insoluble precipitate of cupric hydrate, but this palliative with boilers running at high pressures, and in the presence of organic oils, must be regarded with distrust.

From what has been stated above, it is evident that the measure taken to prevent the presence of copper in the distilled water, by tinning the condenser tubes, causes the temporary disappearance of the copper, because tin instead of copper is dissolved from the inner surfaces of the condenser tubes, and this metal is not readily detected in the distilled

water, whilst directly the tin has been removed by the acid water the copper will once more make its appearance. The use of steel or zinc baffle plates in the head of the evaporator, and zinc protector blocks in the vapour pipe, also cause a temporary removal or diminution of the amount of copper in the distilled water, due to the fact that the baffles, &c., remove, or partly remove, the hydrochloric acid from the evaporator steam, but as the plates become rapidly corroded, they become inefficient and the trouble again appears.

The serious nature of the corrosion which may occur, due to the acid evaporator steam, is well shown from the following extract from a description by an engineer officer of what occurred in a ship using evaporators with steam coils which were not drowned:—

“The brass valves and valve seatings wear in the most excessive manner, in fact it appears as though one or more constituents of the metal were eaten out of it altogether, and only a hard mass left; this remark applies particularly to the vapour valves, through which the secondary (gained) steam passes. . . . It is no new thing, but has been going on for the past three years. The fresh water made always has a metallic taste, and when worked with soap turns a very slightly pale greenish colour; but the fresh water made by a second evaporator which has drowned coils is perfectly fresh, tasteless, and good, and gives no colour with soapy water, although the steam is condensed in the *same* distilling condenser as the unsatisfactory water from the other evaporator.”

DISCUSSION.

Dr. G. D. BENGOUGH, M.A. (Liverpool), in opening the discussion, thought the paper was a most interesting contribution to the history of corrosion, and that the author might reasonably claim to have proved his case that hydrochloric acid was really the cause of the corrosion he had seen on distilling condenser tubes. He had no criticism to offer on that part of the paper. As a matter of fact, he was rather ready to accept that explanation, quite independently of the evidence that the author had brought forward, because he had been investigating for some time an analogous action, and he had come to the conclusion that hydrochloric acid might occasionally be formed in ordinary condenser tubes—not distilling condenser tubes—such as the main condensers of a ship in the mercantile marine. He thought the hydrochloric acid might arise from the hydrolysis of zinc chlorides, and perhaps iron chlorides. He had collected a certain amount of evidence on that point, so that he was more ready to accept the evidence that the author now brought forward in a rather different case. He thought the hydrochloric acid was formed in the case of mercantile marine condensers, rather than in the Royal Navy, because the author had stated that corrosion was obtained in the main condensers of the Royal Navy only in exceptional cases; whereas his (Dr. Bengough's) laboratory showed that there were a large number of cases of corrosion going on in the mercantile marine, his room being a sort of museum of defective tubes. He thought the reason hydrochloric acid formed in some of the mercantile marine condensers and did not form in those of the Royal Navy was that much less care was taken in the treatment of the condensers in certain cases in the mercantile marine than under the very stringent regulations that were issued by the Admiralty to their engineers for the protection of the condenser tubes. He hoped on a future occasion to put before the members some evidence that hydrochloric acid could act very seriously in the case of certain mercantile marine condensers. There were a few questions he wished to ask the author in order to obtain from him a little additional information. He would like to know first of all what form the corrosion took in the condensers—whether it took the form simply of a severe general attack on the condenser tubes, or whether it took the form of pitting and dezincification, giving little copper spots on the tube. He would like to ask the author also whether the distilling condenser tubes were entirely emptied of water when they were not working, or whether the water was allowed to remain in them and just made up from time to time. He also wished to ask how long the corrosion took to show itself: was it a very quick action, or did it take place fairly slowly? In connection with the table given on page 67 the results there given were obtained in 1904; and he would like to ask whether, owing to the fact that drowned coils were now used, the trouble to which reference had been made had entirely ceased?

Sir GERARD MUNTZ, Bart. (Past-President), said he had not much to say, because, like his friend Dr. Bengough, he did not know enough yet about distilling condenser tube corrosion to be able to say much about it. He desired to congratulate the author, not only on his paper but on his candour, because not very long ago he understood the Admiralty never had any trouble with condenser tubes or condensers—that they had obtained perfection, and that they had nothing further to look forward to. It was always of great interest to him when he obtained a little bit of side information giving the experience of the Admiralty on the subject of condensers, and he thought the figures which the author had given pointed to the fact which, speaking as a manufacturer, he had been trying to drill into the heads of people for many years, that the trouble must not always be sought where it was found. By that he meant that when corrosion was found going on in a condenser tube it was by no means certain that the trouble arose in the condenser tube. In the course of the last few weeks he had an opportunity of discussing the matter with various authorities—the scientific specialists referred to at the Dinner on the previous evening—and five out of six distinguished gentlemen from the scientific side had expressed to him, without his asking or suggesting it to them, the opinion that in no case, or in very few cases, had they ever found the trouble in corrosion arose from anything in the constitution of the tube. That was a very wide confession to come from five gentlemen. He would not mention their names, because he did not want to hurt their feelings or commit them for the future; but he gave the members his word of honour that they made that statement to him in the course of the last two or three months. The paper went far to justify their existence as an Institute. It showed how very ignorant the members were, how much they had to learn, how much they had been looking in the wrong direction, and how very fortunate it was that they had an expert like Dr. Bengough engaged in a special research on corrosion, so that they might eventually arrive nearer the truth than they had done in the past.

Dr. G. H. BAILEY (Kinlochleven) said he did not find himself able entirely to agree with the attitude taken up by Dr. Bengough. He did not accept the hypothesis that hydrochloric acid was necessarily the cause of the corrosion, and he did not find from the paper that the author was very keen to believe it himself. It seemed to him that hydrochloric acid had been hit upon as a last resort as the only means of accounting for the removal of copper from the tubes. It had always struck him that the oxygen in the water was a very important factor in such matters. In the first place, it must be remembered that water containing oxygen could actually dissolve copper. The second difficulty which arose was that the hydrate of copper which was formed might be expected to separate out. He was thinking personally more particularly of the copper, because copper was spoken of in the paper. Hydrate of copper in the presence of a certain amount of organic matter, such as would occur on the steam side of the tube, would be easily taken into

solution. The members were perfectly aware that in a colloidal form hydrate of copper would dissolve freely in water. There was thus no difficulty, therefore, in keeping the water charged with a certain amount of copper, provided oxygen was present. If there was no oxygen present, then the chemical expert and the chemist particularly would find a difficulty in arranging formulæ or conditions under which he was able to get the copper into solution without calling to his aid hydrochloric acid. It was also to his mind absolutely convincing, if what he said was true—(and if what he said was true it was a striking confirmation of it)—the fact that drowned tubes avoided the trouble, and that only where air was capable of access did trouble arise. Precisely the same condition of things happened in regard to aluminium. Aluminium exposed to water was acted upon with great readiness, but aluminium exposed to water that had been boiled and from which all the air was expelled was absolutely unacted upon. Aluminium that was exposed to strong salt solution was absolutely unacted upon if there was no air present. He had had aluminium exposed to such water for four months, and absolutely no action had taken place. There was one other point that he hoped he might be permitted to mention. He did not quite gather whether, when the author said that he was unable to determine the presence of hydrochloric acid, because it was so volatile and therefore distillation would affect it, that experiments were done to make quite sure that that statement was a true one. As a matter of fact, the statement in the paper was to the effect that apparently it was not considered desirable—he did not know whether that was the attitude or whether the thing was absolutely tried—to find the amount of hydrochloric acid by distillation because hydrochloric acid was so volatile. As a matter of fact there was the strongest evidence that if weak hydrochloric acid was distilled water passed off, and if strong hydrochloric acid was distilled hydrochloric acid passed off, until a certain balance of strength was reached; but that did not convince him that, with minute quantities of hydrochloric acid, that would be true. A good many years ago now he had a case where hydrochloric acid was alleged to have been produced from boiler water containing magnesium chloride and such materials. In order to satisfy himself as to whether it was possible, even if hydrochloric acid were formed in the boiler, that it would distil over, he took the trouble to make very weak solutions of hydrochloric acid and distil them. He found that, as a matter of fact, no trace of hydrochloric acid passed over until the hydrochloric acid in the retort became comparatively strong. There was absolutely no trace. He would like to ask the author, with regard to the statement that was made about hydrochloric acid, whether experiments of a similar nature were done in order to make it quite sure that it was not possible by distilling with water to get a residue which would be capable of being tested as to its acidity? His own experience would lead him to think that it would be so possible; and if the experiment had not been tried it would certainly be one worthy of repetition. After that lapse of time he could not recall what was the exact strength he used, but he could assure the members

that it was a strength of acid certainly lower than $\frac{1}{10}$ per cent. It was merely intended to show that traces of hydrochloric acid, if in water, would be left behind as a residue after distillation.

Mr. E. L. RHEAD, M.Sc.Tech. (Manchester), said that Dr. Bailey had dealt with most of the points in the paper to which he intended to have referred, and he would therefore confine himself to asking one or two questions. He would like to know first of all whether the author had established the fact that hydrochloric acid would attack copper, and that without the presence of oxygen. The evidence in the paper certainly was not sufficient to give that intimation, or to destroy a well-cherished fact, so far as the members knew at present, that copper was not attacked directly by hydrochloric acid, but that in the presence of oxygen the action went on somewhat freely. So far as the paper was concerned, he thought the question of the drowned coils somewhat established the necessity of an excess of something—air he took it—on the top of the cooling liquor. The second question he desired to ask following upon that was whether experiments had been tried with water. They might be carried out, perhaps, in deaerated water in an oxygen-free atmosphere, in order to prevent air from being taken up by the water. He believed that one of the remarks made by the author with regard to the action of hydrochloric acid upon certain condenser tubes referred rather to brass tubes than to copper tubes.

The PRESIDENT, interposing, said he took it that the tubes referred to in the paper were copper-zinc tubes.

Mr. ARNOLD PHILIP said the tubes were all made of condenser tube composition—copper-zinc.

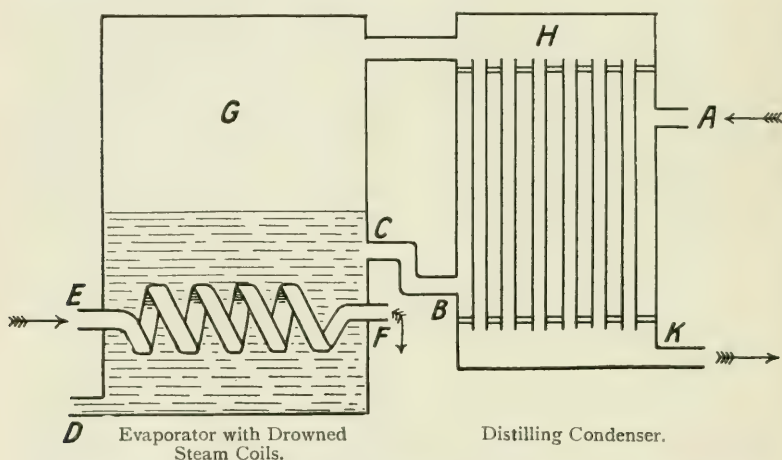
Mr. RHEAD said he was extremely sorry if he had misunderstood the paper, but it certainly gave him the impression that copper tubes were referred to. In that case the remarks he had made *re* hydrochloric acid would not have the same weight.

Mr. ARNOLD PHILIP, in reply, said he was afraid he had rather taken it for granted that the members knew the exact form of apparatus that was used for distilling condensers, and he therefore did not give, as it might have been better if he had done, a diagram in the paper. [Mr. Philip then made a diagram on the board similar to that reproduced on page 74.—Ed.]

The cooling sea water enters the distilling condenser at A and passes out at B, and a portion of it is fed into the bottom of the evaporator at C, and leaves the evaporator in the form of brine, or hot concentrated sea water at D. The brine in the evaporator has a primary steam coil passing through it from E to F. This steam, which may be supplied direct from the boilers, heats up the brine, causing it to boil, and itself becomes condensed, and is pumped away at F to the feed tanks. The steam from the boiling brine passes into the space G. It is known as

the secondary or gained steam, and passes over into the distilling condenser, and is condensed as it flows through the vertical distilling condenser tubes, and is finally pumped away at K to the feed water tanks. The details of arrangement of the primary steam coil flow of cooling water, and method of using distilled water from the condensed primary and secondary steam, are very varied, but the very diagrammatic sketch given below, and this short description, are probably sufficient to make the present paper intelligible.

Mr. Philip said that the chief differences between the distilling condenser and the main or auxiliary condensers—and even these were not fixed differences, it was a matter of practice largely—were, firstly, that such condensers when used for main and auxiliary condensers were as a rule made horizontal, and secondly, whilst in ordinary main and auxiliary



Diagrammatic Sketch of General Arrangement of a Sea-water Evaporating Plant.

condensers, the sea water usually went through the tubes—not invariably, but in modern practice generally. The steam, in fact, was in the space outside the tubes. In the distilling condenser of which he was now speaking, the steam went through the tubes and the sea water circulated outside them. In the ordinary main or auxiliary condenser the scale was inside the tube; in the distilling condensers he was now describing, the scale from the sea water was outside the tubes; otherwise it was quite similar to an ordinary main or auxiliary condenser. He was afraid, from what had been said, that he had not made these points sufficiently clear in the paper, and if so it was certainly liable to lead to some confusion. He would for convenience deal with the discussion in an inverse order. Mr. Rhead considered that it was necessary to demonstrate that hydrochloric acid would not by itself attack copper or metals, but considered the action to be largely due to the presence of oxygen. But

he fully agreed that oxygen must be present. Oxygen was always present in the sea water fed into the distiller evaporator. It was fed in by automatically controlled pumps, or the feed might be controlled by hand; it was heated up by the primary steam, and this steam was separately condensed. Sea water was always alkaline to litmus but neutral to phenolphthalein, and it contained a large amount of air. And when he referred the corrosion he had ascribed to the action of hydrochloric acid he wished it to be understood that air was also always present. It was self-evident from the construction of the evaporator that that was so. The fact that it was hydrochloric acid with the air, and not the air by itself, which caused the corrosion, was fairly clearly proved, he thought, by the circumstance that if the evaporator tubes were drowned, although air was still present in the sea water and came off with the steam, the hydrochloric acid was not generated because the evaporator tubes did not emerge above the surface of the brine, and consequently the corrosion took place. With a different form of evaporator in which no tubes did emerge above the surface of the brine; their exposed surfaces got splashed with the brine, and thick encrustations were formed on them from the salt in the brine, and as the primary steam was at a higher temperature, and sometimes at a considerably higher temperature, than the brine, the dissociation of the magnesium chloride took place on the exposed surfaces of the evaporator tubes, in the space containing the secondary steam and air hydrochloric acid was formed, and corrosion of the distilling condenser tubes took place. To demonstrate that it was not air by itself which caused the corrosion, he relied therefore on the experiments he had described, in which two different forms of evaporator had been successively connected to the same condenser, in the evaporator having drowned tubes, no hydrochloric acid was formed and no corrosion was observed, whereas in the evaporator with exposed tubes free hydrochloric acid was formed and corrosion of the distilling condenser tubes took place. Sir Gerard Muntz had made some very kind remarks, but had credited him personally with having more assurance on the resistance of Navy-type condenser tubes to corrosion than he really possessed. It might be supposed that he must have stated somewhere or other that he had never seen any corrosion at all in condenser tubes. But he did not think this was so. Corrosion did occur even in Admiralty tubes. All he had said was that the percentage of corrosions causing perforation and pitting was very low. There must be some millions of tubes in actual use in the Royal Navy, and a very much larger number in the mercantile marine, and in the latter the number of corrosions obtained was stated to be very considerable. Dr. Bengough said that he had a museum of corroded pieces. The number must, however, be something extraordinarily large if it represented even a very small percentage of the total number of tubes in use in the mercantile marine. The number of pitted corrosions and perforations with which he himself had met formed a very small percentage on the number in use in the Royal Navy, and as a rule the time taken for setting up such corrosion was fairly prolonged. Dr. Bengough asked whether pitting occurred in distilling condenser

tubes. It did, although, as a matter of fact, he had not inspected many of the tubes which had thus been corroded. The trouble as a rule showed itself by the copper appearing in the distilled water. People complained when they had their bath, not that they came out blue, but that the soap came out blue, and that when they made tea it went black, the reason being that the water was boiled in a "copper" (which was really made of iron), the copper being deposited inside the "copper" and iron passing into the water causing the black colouration with the tannin off the tea. To get rid of the copper the practice had been to tin the distilling condenser tubes inside, and this apparently caused the trouble to disappear, *i.e.* black tea was no longer obtained, and there was no blue colour in the bath water, and the evolution of the hydrochloric acid therefore passed unnoticed. Various means of putting protector bars and baffle plates in the head of the evaporator of iron, steel, and zinc also appeared to stop the trouble for a time. With regard to the emptying out of the condensers when not at work, he was not quite sure that Dr. Bengough followed that the steam or inner side of the tubes was always emptied. The condensed steam naturally ran down and was pumped into the feed tank. There was, as a rule, no corrosion at all on the outer or sea-water side of the distilling condenser tubes. As to the action being quick or slow, it appeared at once—that is, the indication of copper in the distilled water appeared at once, and the corrosion must clearly, therefore, take place also at once. He had been very much interested to hear Dr. Bengough's remarks about free hydrochloride acid being the cause of corrosion in the tubes of ordinary condensers. Why he (the speaker) found it difficult to conceive that free hydrochloric acid could effect corrosion in the tubes of ordinary condensers, speaking only of the type used in the Royal Navy, was, because both the corrosion and the deposit occurred on that side of the tube surface over which the sea water flowed. Now the sea water was alkaline to litmus, and thus, according to this view, the corrosion in the auxiliary and main condenser tubes was taking place from free hydrochloric acid on the sea-water side, where an alkaline solution was flowing over the surface of the metal which was corroding. However, a scale was also usually formed on the surface of the metal under corrosion which was also of a basic character, consisting in part of carbonates of lime, magnesia, &c., and it was always, as far as his experience went, rather markedly basic in character, although it did not have an alkaline reaction to phenolphthalein. Dr. Bengough also credited him with having made the same statement as that to which Sir Gerard Muntz referred, namely, that he had maintained there were no tubes in the Navy which corroded. He wished to emphasize the fact very strongly that there were very few involving localized corrosion and pitting, and that those corruptions of this character which did occur were not due, as far as he had been able to ascertain, to the composition of the metal; they were due to other causes. The cause of 80 to 90 per cent. of them was the presence of ashes or some other electric conducting materials deposited in the bottoms of the tubes. If the tubes were used with the sea water out-

side them, and particularly if they were vertical, a very large class of corrosions disappeared at once, whilst if the tubes were in actual metallic contact with the casing with attached protector bars of steel, aluminium, or zinc, or if the casing was of steel, not 90 per cent., but probably 99.9 per cent., of the corrosion which he had seen would be prevented. It was an opinion to be taken for what it was worth, but he thought it was the correct view.

Professor A. K. HUNTINGTON, Assoc.R.S.M. (President), in dealing with the question of the action of hydrochloric acid, said that some little time ago he had a boiler stay sent him which had a composition somewhat analogous to the tubes referred to by Mr. Philip. The stay had had the zinc removed from it in places, and he found that the depth the zinc had been removed was in direct ratio to the thickness of the deposit on the stay. Where there was a thick deposit of scale there the zinc had been removed to a corresponding extent, and where there was very little scale there was very little zinc removed. He came to the conclusion at the time that it was due to magnesium salt in the scale. He did not carry out any investigations on the point, although he thought of doing so, and hoped to do so one day, so that the remarks Mr. Philip had made on the subject were of very considerable interest to him. The particular stay to which he referred had a slot in it in one part which was filled up solid with deposit, and the removal of the zinc was at its maximum there where there was very little access of water. He did not at the moment know the exact position the stay had been in, whether it was totally immersed or partially exposed. It would accumulate more deposit on the top side than on the bottom, and the part showing the removal of the zinc had presumably been on the upper side.

He thought the members were extremely indebted to the author for his paper, which was a very useful contribution to the corrosion question, which they were all so much interested in, and he desired to propose a hearty vote of thanks to him for the paper.

COMMUNICATIONS.

Mr. H. J. YOUNG (Wallsend-on-Tyne) wrote that he had met a similar type of phenomenon when dealing with the residues from marine boilers and steam chests. If these residues were heated in a test-tube at a comparatively low temperature vapours came off which were acid to litmus. In some cases he had been unable to detect either chlorides or sulphates in the residues, yet in all cases under his notice the acid vapours had been evolved. He remembered one residue composed merely of the oxidized elements of cast iron together with free iron and carbon, and mineral oil of very low acidity, and no chlorides or sulphates whatever. He thought Mr. Arnold Philip had opened out a subject not only of great interest, but also one of immense importance

to more than the non-ferrous industries, and the remarks he had made above were merely introduced with a view to pointing that out.

Mr. ARNOLD PHILIP wrote that on reading over the printed discussion he had been impressed by the fact that both Dr. Bailey and Mr. Rhead still appeared to doubt that the corrosion he had described was due to the action of hydrochloric acid in the presence of air; indeed the former speaker even considered that he, the author, was not convinced that the theory he had himself proposed was correct. He wished therefore to emphasize the fact that in his opinion the statements he had made in the paper gave an overwhelming proof that the observed corrosion was due to hydrochloric acid, and he could not help feeling that if Dr. Bailey would make a careful perusal, outside the atmosphere of discussion, of what he had recorded even he would become convinced.

With reference to Mr. Young's remarks he feared that the circumstances of the case which he referred to were too incompletely known, or not sufficiently fully described, to permit of it being treated as an example of the same kind of action as that with which he had dealt in the paper.

THE CORROSION OF ALUMINIUM.*

BY G. H. BAILEY, D.Sc., Ph.D.

TAKEN in its widest sense, the question of the corrosion of aluminium is much too large to be dealt with in a single communication. Furthermore, it is of a diverse nature both in regard to methods of inquiry and to results, so that when we examine the action of the atmosphere or atmospheric agencies, the action of water under varying conditions and purity, the action of mineral or organic acids, of alkalies and alkaline salts, and of organic liquids, we are confronted with a series of sectional and more or less independent investigations. In the present communication I propose to confine myself to the consideration of the corrosion of aluminium by water and by solutions of common salt, and to give some of the results of investigations with which I have been from time to time engaged during the past three years. The literature connected with this subject, some references to which are given at the end of this paper, is already quite considerable, and I do not intend to refer to it in detail. Many of the experiments that have been published are, however, open to criticism, partly on account of the methods employed and partly in consequence of the material upon which the experiments have been made, and hence the conclusions that have been drawn are apt to be misleading.

There are, for instance, investigations from authoritative sources in which the rate of corrosion is determined by reference to the *weight* of metal employed, when manifestly this factor must be referred to the *surface* exposed to action. In some cases the value attaching to estimates is lessened by the consideration that the samples of metal used were of a very low grade of purity—usually under 99 per cent. purity—whereas the bulk of the metal which is supplied for commercial use, in this country at all events, is of 99 per cent. to 99.5 per cent. purity. Moreover, impurities which are still liable to exist in the metal, such as sodium and copper, and which have a very

* Read at Annual General Meeting, London, March 12, 1913.

marked effect on the extent of corrosion, are apt to be ignored in the investigation of corrosion, whilst other impurities whose effect is usually negligible are given too large a significance.

An interesting series of determinations bearing upon the effect of copper on corrosion appears in the 8th Report of the Alloys Research Committee, by Carpenter and Edwards, pp. 216 and 254.

ESTIMATION OF THE EXTENT OF CORROSION.

The first step towards obtaining some definite knowledge relating to the corrosion of aluminium must involve the adoption of a method of ascertaining with approximate accuracy the amount of metal removed or acted upon during the exposure, and it is perhaps of greater importance that the method adopted should be capable of use in the hands of different experimenters and yield comparable results than that it should be rigidly accurate.

If aluminium sheet be exposed to the action of water for some days, it will be found that the water becomes slightly turbid owing to the formation of hydrate of alumina. On the sheet being removed and the surface rubbed, a further amount of such solid matter is obtained. It is seldom, however, that the whole of the adherent deposit can be removed by rubbing, for the sheet will, even after such treatment, usually be found to be slightly heavier than it was when first placed in the water. The deposit on its surface, though essentially alumina, varies in character and composition according to the nature of the aluminium sheet and of the water employed, and, with impure waters, may contain some matters derived from the water itself.

Messrs. Heyn and Bauer (Königliches Materialprüfungsamt Gross Lichterfelde West) recognized the difficulty of removing and estimating such deposit, and determined the adherent portion (which is as a rule larger than the amount suspended in the water) by exposing the sheet subsequently to the action of dilute sulphuric acid, evidently on the assumption that the acid would dissolve the deposit without notably attacking the metallic aluminium.

Unfortunately, the reverse is the case, for usually the exposure necessary to remove the deposit is so prolonged that it is quite impossible to ignore the action of the acid upon the aluminium, nor have I found it practicable even by a consecutive series of immersions and weighings to arrive at the amount of the deposit in this way. The association of chromic acid with sulphuric acid hastens the removal of the deposit, but does not attain the desired result. Other reagents and other means have been tried, but without any satisfactory issue. I have therefore in my experiments used the method now described.

METHOD FOR DETERMINING RATE OF CORROSION.

A sheet of aluminium, of at least 100 square centimetres surface, is cleaned by the application successively of ether, dilute caustic soda, and dilute nitric acid, subsequently being well washed and heated for some hours at about 100°C . to get rid of moisture. It is then weighed, the weight being taken as W .

It is now *totally immersed* in say half a litre of water, or solution, at a known temperature, and left with occasional agitation for at least forty-eight hours.

The sheet is then removed and, so far as possible, cleared of deposit by rubbing. The whole of the substance so removed or previously suspended in the water is filtered off, ignited, and weighed. With good ordinary sheet this material consists almost entirely of alumina, and in view of minor corrections, which need not be referred to, may be taken as representing half its weight when expressed in the form of metal. The weight so found being represented as w , it is evident that, ignoring the adherent deposit, the sheet should now weigh $W - w$.

Now expose the sheet for some hours to a temperature of about 200°C . to render alumina anhydrous, and weigh it. This new weight being represented as w' , the expression $w' - (W - w)$ gives the amount of adherent deposit, and this similarly is reduced so as to be expressed in the form of metal.*

* The total aluminium removed by corrosion may, for practical purposes, be more simply expressed as three-fourths of the weight of suspended and removable matter added to one-half of $(w' - W)$.

With very impure metal, or when very impure waters or solutions are employed, the residue obtained in both cases may be of more complex character, and must be submitted to further examination. But in general the amount of metal removed may be ascertained from the above factors. An actual example will make the matter clearer and indicate the order of magnitude of the materials dealt with. A strip of aluminium sheet, whose weight was 6.4978 grammes and surface 150 square centimetres, was exposed to good tap water at boiling temperature for eight days; the suspended deposit weighed 10 milligrammes; the sheet after rubbing weighed 6.5062 grammes. The deposits amounted to 10 and 13.4 milligrammes respectively, and the metal removed by the action of the water was thus 11.7 milligrammes. This represents a rate of corrosion amounting to very nearly 1 milligramme of aluminium per day per 100 square centimetres of surface exposed.

NATURE OF CORROSION.

An examination of the liquid in which the metal has been placed shows that, except in waters containing free acid or alkali in notable quantity (and such waters are rare amongst domestic supplies), *no aluminium whatever passes into solution, and that the corrosion is purely a question of oxidation of the aluminium to alumina at the expense of the oxygen dissolved in the water.* This important result may be further established by exposing the metal to water from which the air has been expelled. Samples of aluminium sheet have indeed been exposed under such conditions, not only to water but also to a strong (15 per cent.) solution of common salt for several months without undergoing any corrosion. It follows also from this of course that, especially if the surface of aluminium be large in comparison with the volume of water used and no measures are taken for renewal of the air contained in the water, the rate of action gradually diminishes.

This is most strikingly the case when hot, and particularly boiling, solutions are used. For instance, a sample of sheet exposed to the action of water at about 95° C. for thirty days showed a rate of corrosion—

During the first day equal to 3.3 milligrammes per 100 cm. ² per day.							
,, next 7 days equal to 1.2 milligrammes per 100 cm. ² per day.							
,,	11	,,	0.3	,,	,,	,,	,,
,,	11	,,	0.1	,,	,,	,,	,,

This falling off is also partially due to the protective action of the deposit formed on the surface of the metal, so that vessels or tubing exposed to continuously heated water undergo very slow corrosion.

LIMITATIONS OF THE METHOD.

Determinations made by the method described above serve only to ascertain the amount of the metal removed by corrosion, and have little direct bearing on the specific nature of the physical phenomena or other exceptional conditions often associated with corrosion. Nor do they afford any explanation how it comes about that two particular samples, substantially of the same composition, may show somewhat different rates of corrosion; or to what extent the attack on the metal is evenly distributed over the surface, or more or less confined to pitting and small areas. Such problems, however, cannot be elucidated except by the application of special and independent methods of inquiry.

The simpler question dealing alone with the extent to which good and well-annealed aluminium sheet is acted upon by various potable waters or solutions or reagents is one of supreme importance in regard to the commercial uses to which aluminium is put. I am also quite prepared to admit that in minor details the method proposed may be open to criticism, and that the values it gives are in all probability somewhat too high. A considerable experience of its application in practice, however, indicates that under the variations which occur normally in the course of investigation and also in the hands of different observers comparable and reliable results are obtained.

EXPERIMENTAL RESULTS.

Below are given the amounts of corrosion of metal, having various grades of purity and character, during exposure to

water and solutions of common salt. I have also added, although this contribution is not intended to deal with the action of acids and alkalies, a few instances illustrating by way of comparison the rate of corrosion by weak solutions of some acids and of caustic soda. Though in the earlier part of the paper I have expressed the results in milligrammes per day per 100 cm.², the data given below are stated in grains per day per square yard of surface.

Index Figure and Composition of Samples.

Index Figure.	Silicon per Cent.	Iron per Cent.	Aluminium per Cent.	Remarks.
1	0.26	0.47	99.27	...
2	0.17	0.18	99.65	...
3	0.19	0.28	99.53	...
4	0.26	0.31	99.43	...
5	0.30	0.52	99.06	0.116 per cent. sodium.
6	0.30	0.49	99.12	0.09 " "
7	0.58	1.25	98.17	...
8	0.59	1.84	97.57	...
9	0.20	0.60	99.20	Unannealed.
10	0.23	0.20	99.57	"
11	0.20	3.22	96.58	"
12	0.64	0.37	98.99	...
13	0.37	0.23	99.40	...
14	0.23	0.18	99.59	...
15	0.21	0.35	99.14	0.30 per cent. copper.
16	0.21	0.29	98.96	0.54 " "
17	0.21	0.30	98.61	0.88 " "
18	0.32	0.50	95.48	3.70 " "

Samples exposed to the Action of good Tap Water.

Index Figure.	Amount of Corrosion at		Remarks.
	10° C.	100° C.	
1	1.0	3.3	...
2	0.75	2.6	...
3	0.85	2.6	...
4	0.80	3.0	...
12	0.85	2.5	In metal where the silicon exceeds the iron the corrosion products are almost entirely adherent to the metal.
13	0.75	2.6	
14	0.45	2.0	Sample containing copper.
15	1.90	...	
16	1.87	...	" " "
17	1.34	...	" " "
18	6.70	...	" " "

Samples exposed to Solution of Common Salt.

Index Figure.	Amount of Corrosion at Various Concentrations.						Remarks.
	At 10° C.				At 75° C.		
	1 per Cent.	5 per Cent.	10 per Cent.	15 per Cent.	3 per Cent.	15 per Cent.	
1	1.5	2.8	4.5	...	...	...	...
2	4.3	...	...	19.3	...
3	1.3	2.0	4.0	...	11.3	...	...
4	...	1.4	...	...	10.3	...	...
5	15.0	...	Contained much sodium.
6	18.6	...	" " "
7	13.0	...	...	...
8	15.9	...	...	...
9	25.8	...	...	Unannealed.
10	24.0	...	...	"
11	55.5	...	...	"
12	...	8.5	...	...	...	...	...
13	...	6.5	...	...	...	...	...
14	...	6.0	...	...	...	...	...
15	...	3.84	...	...	...	...	...
16	...	4.23	...	...	...	...	Contained copper
17	...	4.30	...	...	...	...	" "
18	...	12.87	...	...	...	...	" "

They may be converted into the metric form by dividing by 1.29. It may be added that a corrosion amounting to 10 grains per day per square yard, *i.e.* 10 units, as stated above, implies the removal of a film $\frac{1}{40}$ th part of an inch in thickness of metal by continuous action extending over a whole year.

Samples exposed to very bad Tap Water.

These waters contained exceptionally large quantities of mineral matter, including alkalies; they had a distinctly alkaline reaction.

Index Figure.	Amount of Corrosion at Various Temperatures.					
	Water A.		Water B.		Water C.	
	10° C.	75° C.	10° C.	75° C.	10° C.	75° C.
1	2.3	15.8	3.2	23.2	3.3	19.3

Comparative Statement of Rate of Corrosion by Acid and Alkali.

Index Figure.	Good Water.	Decinormal H_2SO_4 .	Decinormal HCl.	Decinormal NaOH.
1	1.0	3.5	21.0	770
4	0.80	10.0	35.5	708
12	0.85	7.7	29.8	898
13	0.75	5.0	19.0	868
14	0.45	6.1	11.9	836

GENERAL CONCLUSIONS FROM FOREGOING RESULTS.

1. That in general the greater its degree of purity, aluminium is less acted upon by water and salt solutions.

2. That in presence of copper or sodium the corrosion is notably accentuated.

3. That where the percentage of silicon is higher than that of the iron the action is less pronounced in the case of water and acids, and more pronounced in salt solution.

4. That water and common salt solution, from which air has been expelled, have no corrosive action.

5. That corrosion is accentuated (*a*) at high temperatures, (*b*) by the presence of impurities in the water, especially alkalies.

6. That unannealed metal is much more seriously corroded than annealed metal, owing no doubt to the unequal physical condition of the metal in the unannealed state.

7. That the results obtained by acting on aluminium with acids or alkalies afford no definite indication of its behaviour in presence of water or aqueous solutions. Had it been possible to establish any parallel, the investigation of the corrosion of aluminium would have been much simplified, since the difficulties presented by the formation of suspended or adherent deposit would be eliminated.

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DISCUSSION.

Dr. G. D. BENGOUGH, M.A. (Liverpool), in opening the discussion, said that Dr. Bailey, in referring to the remarks that he (Dr. Bengough) made on the last paper, said that he under-estimated the important part that oxygen played in corrosion. He did not do so at all. He entirely agreed that oxygen played a very important part in corrosion, not only in the case of aluminium, but also in the metal he was investigating, namely, brass; in fact, he believed the primary action in the corrosion of brass was the formation of copper and zinc oxides, secondary reactions taking place and resulting in the formation of basic salts. So far was he from underrating the importance of oxygen on the question of corrosion, that he felt convinced that the author's account of the oxidation and the relation between oxidation and corrosion of aluminium was correct. He thought the author's method of estimating the amount of corrosion was sound and satisfactory, and, with possibly small errors that might be obtained in the method, it would come well within other inaccuracies that might be obtained in connection with the very difficult investigation of corrosion quantitatively. From what the author had said in connection with the paper, he thought the course of the corrosion ran very parallel indeed between aluminium and brass. The factors that the author found affected the corrosion of aluminium, he (Dr. Bengough) found affected the corrosion of brass. The author found that the rate of corrosion with aluminium fell off as time went on. He (Dr. Bengough) had found exactly the same alteration in the rate as time went on with brass. The differences between the two cases were largely due to the fact that in the case of brass they were dealing with very adherent oxides which did not fall off readily, whereas in the case of aluminium they were not adherent. They also got secondary reactions, particularly in connection with zinc, which did not occur in the case of aluminium. He had not investigated aluminium at all, but he fully accepted what the author said on the subject. In brass they got zinc going into the solution (but not copper), so that the case was very analogous to the one described by the author. They had less difficulty than Dr. Bailey in one way, in that, although they had secondary reactions to investigate, they had not the same trouble in investigating the loss of weight, because the films of oxide that were formed were very thin and perfectly adherent. In one way they were better off, but in another way they were worse off, because they still had further things to investigate. There was a fair parallel in certain features with the corrosion of brass, and the phenomena that he found differed in some ways from the phenomena which were accepted pretty generally in connection with the corrosion of metals. The idea of direct oxidation was anathema in certain quarters in physico-chemical studies, but the author had evidently come to the conclusion that oxidation which appeared to be direct was a very important point in corrosion, and he had been gradually coming to that conclusion himself in connection with brass. So that in certain respects they stood shoulder to shoulder against the

pretty big body of physico-chemical opinion, though conclusive proof was still lacking.

Dr. R. SELIGMAN (London) wished to say, in the first instance, that he thought the author's complaint that so many corrosion determinations were made with reference to weight, was fully justified. It was a very unscientific method of dealing with the question, and did not lend itself to comparison in any way. At the same time he thought those who threw stones ought not to live in glass houses, and he did not know that it helped the members to compare the results of the author with those of other workers to talk of "good tap water" and "bad tap water." That was not a very accurate description of the materials used. The next question which he desired to touch on was the list of papers given by the author at the end of his communication, in which he referred to some of the previous workers on the subject. When he came to look at the conclusions arrived at by the author, he found that four of them were conclusions arrived at by one of the authors whose works were thus referred to. Those who had read Heyn and Bauer's paper would remember that they were the first to prove that if air was kept out of the solutions no corrosion took place. They carried on their experiments, if he remembered rightly, for about four or five months, and found no corrosion at all when air was excluded. Then they also laid it down that corrosion was accentuated by high temperatures, and they also gave a very long list of experiments on the effect of impurities in the water. Then they discovered—he thought it was a very valuable discovery—the effect of the physical state of the metal, *i.e.* whether it was annealed or unannealed. He thought therefore that the author would not have strained his generosity if he had referred to Heyn and Bauer rather more explicitly. Similarly, in regard to the author's third conclusion, as to the percentage of silicon and its effect, that matter was dealt with by Formenti about eight or nine years ago, who also showed the protective action of silicon in stopping corrosion by water. There was one difference he noticed (to which Dr. Bengough referred) between the author's results and those of Heyn and Bauer. Heyn and Bauer made the statement that the first action in the corrosion of aluminium by water was the solution of aluminium, and subsequently oxidation took place at the surface of the liquid, but Dr. Bailey stated that no solution took place. He would like to ask the author whether he had done any definite experiments on that point, because there was nothing in the paper to guide the members as to whether that was correct or not. It seemed to him an extremely difficult question to solve, and therefore one required to be careful in making the statement. He now desired to deal with a point which he ventured to think was of very considerable importance. The author said on page 83 that his method was exclusively intended to determine the amount of aluminium removed or oxidized during corrosion. It pretended to do nothing else, and the author stated so very clearly. But in the next paragraph he noticed the author said that determina-

tions so made on well annealed aluminium were of extreme importance from the point of view of the durability of the metal. There he found himself absolutely at variance with the author, basing his view on a considerable experience of the metal. When one was discussing the corrosion of aluminium by water and such solutions as the author was dealing with, the gravimetric determination of the amount of metal oxidized was of no importance whatever with regard to the durability of the metal. If aluminium was poisonous, or gave off anything poisonous to water, then he thought the author's statement would be correct, and they would want to know how much poison got into the water. But it was well known that aluminium was not poisonous. If one was dealing with the solutions in question, the only thing one wanted to know was whether the corrosion was going on locally or whether it was going on generally. The amount of material removed was quite without importance on that point, and in spite of that the author on a subsequent page argued from his results that it implied the removal of a film $\frac{1}{240}$ th part of an inch in thickness of metal by continuous action extending over a whole year. [The author here demurred, and Dr. S. read the following statement from the paper:—"It may be added that a corrosion amounting to 10 grs. per day per sq. yard, *i.e.* 10 units as stated above, *implies the removal of a film* $\frac{1}{240}$ th part of an inch in thickness."] He thought that was an extremely dangerous fallacy which he could best explain by giving an example. For that purpose he had brought with him a little piece of aluminium plate which had been in strong nitric acid for a year. In that case there had undoubtedly been the removal of a film of metal, and it had been so uniformly removed as not in any way to affect the appearance of the metal [specimen produced]. That was a corrosion which one was able to calculate and to reckon with. It was clear that if a plate of a certain thickness was taken, it was possible to calculate its life within a reasonable figure, and if its thickness was doubled its life also would approximately be doubled. The sheet to which he had referred had lost 40 milligrammes per 100 square centimetres per day, *i.e.* 40 times as much as the author's. On the other hand, he had also brought with him a little piece of aluminium which formed part of a pipe, and which had been in what Dr. Bailey would probably call good tap water for a short period of months. There the local action which took place in the water would be seen. The inside was being attacked in places while the majority of the surface was altogether unattacked. Here and there action was going on to a very considerable depth. In such a case as that, he wished to know what importance it could possibly be how much metal had been lost. If it had all been lost in the area of a pin's head, the loss of weight was of no importance whatever, in his opinion, and he did not see that it mattered whether it was measured in grammes per square yard, or in scruples per square pole, or anything else. He felt rather strongly on that point, because he thought all were agreed that aluminium in the past had suffered very seriously on account of shutting their eyes to the disadvantages which the metal suffered from, and the

dangers to which it was exposed. He could not believe that the progress of the metal was to be advanced in that way, and for that reason he took the strongest possible exception to any statements such as those to which he had drawn attention, which might lead, however unintentionally, to a false sense of security.

Mr. S. L. ARCHBUTT (National Physical Laboratory) said that he appreciated the opportunity of making a few remarks with regard to Dr. Bailey's paper. With regard to the method—the times of immersion were surely too short, and hardly justified conclusions as to the probable behaviour of the material during much longer periods such as would obtain in service. The experience of Dr. Rosenhain and himself was that the formation of a protective coating or patina might have a considerable influence on the rate of corrosion which could only be determined by much longer periods of immersion than those used. The author himself drew attention to the marked influence of such a protective coating on page 83. Values obtained from such short periods of test were rather to be considered as representing initial corrosion of the material, and it was open to question whether they might be taken as a measure of its subsequent behaviour. Further, in calculating the total aluminium lost, by the method given, it appeared necessary to assume that the hydroxide of aluminium which could not be removed from the sheet by rubbing (and which in the example given on page 82 was in excess of that removed) was entirely converted into Al_2O_3 by heating the sheet to 200°C . Apart from any evidence which Dr. Bailey could give them to the contrary, there seemed to be considerable doubt as to whether this adherent alumina would be completely dehydrated by such treatment. If it was not, the method of calculation employed might lead to errors having considerable influence on the results, especially if used for predicting behaviour over very much longer periods. The observation that where silicon was in excess of iron, the corrosion products were almost entirely adherent was very interesting. Finally he should like to ask the author exactly how the specimens were immersed. His experience had been that no matter what the material support, wood, glass, rope, etc., corrosion was accelerated wherever the alloy came into contact with it, and it seemed that friction might play an important rôle in the matter.

Mr. ARNOLD PHILIP, B.Sc. (Member of Council), said he happened to have some figures with him for corrosion, not of aluminium, but aluminium containing 3 or 4 per cent. of cadmium, and he found that so far as the amount of corrosion of suspended samples was concerned they were of the same order as those given in the author's results. The corrosion tests he had made were carried out in sea water. He was not quite clear why a temperature of 10°C . had been selected by the author instead of the usually accepted normal temperature; sea water was the solution which he had had to deal with, and the resistance of material to corrosion in sea water was the important question for naval work.

There they had oxygen and a certain fairly definite average composition, and the Admiralty practice had been to examine corrosion in sea water at an average temperature of roughly about 15° C. The tests that he now described were made on the alloy firstly by suspending it in sea water by a cotton thread. Unfortunately in engineering work it was impossible to have aluminium by itself; it had to be supported on something else. It was either in contact with gun-metal or steel, or perhaps some other white metal bearing. To take these factors into account, therefore, four different methods of test were used. First of all, as he had stated, the metal was suspended on a thread of cotton; it was also (*b*) tested in contact with steel; (*c*) in contact with Admiralty gun-metal; and fourthly (*d*) in contact with Admiralty gun-metal whilst subjected to a rubbing test. The figures were as follows:

Duration of Corrosion in Days.	Total Loss of Weight in Milligrammes per Square Inch of Surface.	Nature of Support of Test-piece of Aluminium Alloy.	Loss of Weight in Grains per Square Yard of Surface per Day.
73	2.6	Cotton	0.7111
91	61.7	Gun-metal	13.54
91	44.3	Steel	9.71
6	61.6	Rubber in contact with Gun-metal	204.9

The figures he gave did not give the amount of corrosion in the scruples per acre to which a previous speaker had referred, but he agreed that he had also used absolutely indefensible units. The unit he had used was fixed, and might perhaps be excused by the fact that the weights he possessed were gramme weights, and it was therefore easy to put the results down in milligrammes; he also possessed inch scales close at hand, and as engineers were accustomed to working in square inches, he had used these units. A report was required in a hurry, and the figures were put down in the most convenient form of measurement at hand.

The rubber referred to in the result given on the last line of the table was made of an open-work cotton fabric. He thought it would be of interest to put forward these figures as showing that, on the whole, they were of the order of the figures which the author had found. Under what were very similar conditions of test, namely on page 84, the author stated that at 10° C. in good tap water the corrosion loss in grains per square yard per day was 1.75, 0.85, 0.81, 0.45, which results were of the order of the 0.71 loss he had recorded on the top line of the table he gave. If he might offer one criticism on a very useful paper, he would point out that the author's results were in almost all cases based on single tests only, and his experience of corrosion was that it was very desirable to make a large number of tests under as far as possible absolutely similar conditions, in order to eliminate anything in the nature of accidental in-

terference. Incidentally Dr. Bengough had remarked that just as Dr. Bailey had observed a closely adherent coating of oxide of aluminium formed on the samples he had examined, which coating could not be removed by friction, so he had observed a similar patina of red oxide of copper formed on brass. He (the speaker) wished to say that his own experiments with brass alloys confirmed this observation; it was useless to try and remove this patina by friction, and chemical means were very much to be suspected as affecting the weight of the material. He had some samples with him of aluminium containing 3 per cent. of cadmium which he would leave on the table for the inspection of the members. One of them was of great interest, because he found that some rolled samples of aluminium blistered badly during corrosion, and in judging of the amount of corrosion for practical purposes it was necessary to include the scale of aluminium metal that came off from such blisters, which must be regarded as part of the corrosion. The sample after corrosion and external cleaning weighed largely in excess of its original weight, and it was possible to see at some points the cakes of basic chloride of aluminium, and he did not know what, under the blistered layer of thin aluminium, and this explained the increase in weight of the sample under test. The blistering effect was very remarkable. The sample he showed was a piece of aluminium alloy containing 3 per cent. of cadmium that had been drawn into a tube.

Dr. F. J. BRISLEE (Liverpool) said that he was inclined to disagree with the remarks Dr. Seligman had made on one point. He thought it was better to have some quantitative measure of corrosion than none at all, and it was extremely difficult to get any of those particular instances, as they all knew. He agreed with him most emphatically on one point, namely, that the paper which the author had referred to by Heyn and Bauer pointed out one important fact which he did not think had been brought out so far in the discussion, namely, the nature of the deposit which occurred on the metallic aluminium. They pointed out that, when aluminium was immersed, say, in a water containing calcium salts, the precipitate also contained calcium. Whether they were justified in weighing that precipitate and calculating back the metallic aluminium, was a point that was open to the gravest doubt. He was rather astonished, a short time ago, to discover that aluminium, in the presence of a very dilute solution of caustic soda, was almost quantitatively converted into aluminium hydrate, which separated out at the bottom of the tank, scarcely any of the aluminium going into solution. On the other hand, if a small quantity of calcium sulphate was added, the reaction was different, with the result that he could not say that the precipitate was aluminium hydrate, but contained a notable quantity of calcium hydrate and calcium oxide in addition. The mechanism of the reaction is as yet not worked out. Without knowing it he was working on very similar lines to the author, but unfortunately his results were entirely vitiated for the above reasons, and for the time he felt rather bowled out. Like Dr. Seligman, he was more imme-

diately concerned with certain of the industrial aspects of aluminium. It was a metal of unique disadvantages, so unique that, if it had not been for its electrical conductivity, it would have been as dead as the proverbial door nail. Frequently an aluminium vessel, probably a domestic utensil of some sort, was handed to him, and he was asked to account for its awful appearance: the aluminium appeared to have gone into pits—not uniformly corroded. Samples could be taken from it all over, and it would be found on analysis reasonably pure, anything between 99·3 and 99·5 per cent., and yet the pitting was indiscriminating. It had gone into pinholes, and the vessel, as a vessel, ceased to be of any use whatever. What was the cause of it? If he remembered rightly (Dr. Seligman would correct him if he was wrong, because he had a much greater experience of aluminium vessels), so far as his experience went, the corrosion was not worse between wind and water, where the oxidation should be greatest. On the whole, however, he was inclined to agree with the author's conclusion that the oxygen did play an all-important part in the change. He thought they could all agree on the subject of the protective coating, in which he was immediately concerned, particularly where aluminium was exposed, not to the direct action of liquids but to spray. There, from an experience extending over three years, he had seen aluminium in the form of rod corroded very considerably, and then stand up to its work, for the remaining time, without any trouble whatsoever, and it was working at the present moment in an entirely satisfactory manner. He was inclined to think that, if only the exact conditions could be found, the coating was acting protectively; and he knew of at least one patent at the present moment for the electrical insulation of aluminium wire by depositing on it a flexible coating of aluminium oxide. He had seen armature coils wound with it, and had been very much astonished to find that the aluminium oxide under those conditions was flexible enough to allow the wires of, say, something about 18 or 24 standard wire gauge, to be wound on a spool a little more than 1 inch in diameter. He desired, before sitting down, to thank the author for having brought forward the paper dealing with a subject which hit so many of those present extremely hard.

Professor T. TURNER, M.Sc. (Hon. Treasurer and Vice-President), desired to make a few remarks on the general subject of corrosion tests. He had often felt a doubt, when he had put a specimen into a liquid, and desired to see what the effect of corrosion would be, as to whether the specimen that was put into the liquid fairly represented the material that was under test. For example, the members had to do largely with castings in the metal trade. Those castings had a skin, and tests of the kind which the author had conducted had no reference to the question as to whether or not that skin was a protection. He was not in any way reflecting upon the author's work; it was simply an inherent difficulty that everyone met with. In other cases metal left the manufacturer's hands that had been cold-worked, and into which oil had been pressed. A certain amount of that oil penetrated into the

surface pores of the metal and helped to protect it. In other cases the metal had been heated; it had been finished hot from the rolls, or had been annealed. Some of the advantages that were claimed for annealing might be, and very possibly were, due to the kind of surface that had been produced as the result of the heating. If a piece of brass which had been rolled was heated again and annealed, it had very curious markings or discolorations, and that must affect the electrical character of the surface. An endeavour was made, before carrying out a corrosion test, to get what was regarded as a normal state of metal. It was desirable to clean it from grease, from scale, and so forth, and the author had adopted a good method for that purpose. He had treated it first with ether to remove the grease, then with dilute caustic soda to finish that part of the purification, and then with dilute nitric acid. He had no doubt that, when a metal such as copper was treated with nitric acid, even if the surface was washed repeatedly with distilled water afterwards, there was still a different condition in the surface of that copper, and some of the nitrogen was retained in the surface. If the copper was heated in a vacuum, it would be found that different gases would be produced. A very simple way of testing it was to take two sheets of copper-foil, place them on a piece of glass; then take one in the ordinary way and heat it to 200°C ., and the particular effect of transparency due to oxidation, to which he had referred in previous years, would be found. But if one sample had previously been treated with very dilute nitric acid, even though it had been washed repeatedly, it would be found that it would oxidize more rapidly than the original sample. In the author's experiments, when there was a deposit on the surface, before it could be examined the deposit was removed by rubbing—he presumed with the finger. If that was the case, there was a certain amount of grease from the finger put on the surface. Or it might be rubbed with very fine emery, and some of the emery particles would be pushed into the metal. It might be rubbed with a glass rod, which would harden the surface in lines, and give a metal that was more positive than the rest; and wherever there was a little scratch where the glass rod had rubbed the surface, it would give a different electromotive-force to the rest of the metal. The subject was an exceptionally difficult one, not only as applied to any tests that the author might have conducted, but it was a question that was in his mind whenever he attempted to supervise any experiments on corrosion. He found it extremely difficult to satisfy himself that the tests really corresponded with the kind of test which the metal would have to undergo in practice, or that he had not seriously altered the conditions by his attempts to prepare the material.

Dr. A. G. C. GWYER (Milton) said that he desired cordially to associate himself with Professor Turner's remarks, and that he too had been interested in the method by which the author had cleansed his sheets, notably with caustic soda. When a sheet was treated with such a chemical the polished surface was dissolved away, leaving the body of

the metal more porous and prone to general corrosion, and that was one cause which would tend towards unduly high results. There was no doubt but that in the final stages of the polishing and burnishing processes, a thin amorphous layer of metal was flowed, as it were, over the surface of the sheet, as Beilby had shown, and that theoretically this, being an unstable modification, would corrode more rapidly than the ordinary metal. But in his (the speaker's) opinion this was not in practice strictly true, because the presence of this amorphous skin acted as a protective against corrosion by flowing over and closing up the pores of the metal.

Another point he was specially interested in was the corrosion of the specimens which contained 0.09 per cent. and 0.11 per cent. respectively of sodium. These specimens when corroded in salt solution gave the numbers 18.6 and 15.0 respectively at 75° C. Yet curiously enough, at only 10° C., the relatively high silicon aluminums gave 8.5 and 6.5, which seemed rather excessive in comparison. He would like to know what explanation the author had to offer. He thought the effect of sodium would be more pronounced, and that of silicon rather less pronounced, in salt solution. The paper clearly showed that the predominance of silicon was advantageous, because not only was the corrosion less in the case of tap water, but the products of corrosion were almost entirely adherent to the metal. If the aluminium hydrate was suspended in the solution, it was the same thing as the metal corroding.

He very heartily subscribed to expressing the results so as to take full account of the area of surface exposed, because the specific gravity of aluminium was so low in comparison with that of the common metals. In the case of, say iron or brass, for equal areas, the actual weights would not be so very different, whilst in the case of aluminium the weight would be only about one-third, roughly speaking. This was important, particularly in view of Dr. Rosenhain and Mr. Archbutt's recent work, which had led them to introduce the term "specific tenacity," as affording a means of comparing the tensile strength of the light alloys of aluminium with that of other metals, *weight for weight*.

Mr. E. F. LAW (London) said that he wished the author had been able to give a few more data. He finished his paper by giving what he called his "general conclusions from foregoing results," but, with due deference to the author, he did not think the results given in the paper justified these conclusions. He was not finding fault in the least with the conclusions; he was inclined to think they were right, but he submitted that the results given in the paper did not support the conclusions. For example, the very important second conclusion, "That in presence of copper or sodium the corrosion is notably accentuated," was unsupported by figures. On looking at the analysis of the alloys he could not find that any copper was given at all, and sodium was given in only two cases. Not only was copper not mentioned, but there was no allowance for copper in the analysis, the aluminium having obviously been estimated by difference.

He did not think the author was wrong for an instant, but he did not think he was justified in stating it as a general conclusion drawn from the foregoing results. The same remark, he thought, applied to conclusion No. 3, "That where the percentage of silicon is higher than that of the iron the action is less pronounced in the case of water and acids, and more pronounced in salt solution." He did not think the author's figures quite bore that out, and in any case the results recorded were too few to justify the conclusion. He agreed with Mr. Philip that a greater number of determinations were necessary, and that these should be done in duplicate. Before concluding, he desired to emphasize what Dr. Seligman had said with regard to expressing results in terms of loss of weight. That method did give a figure, it was true, but it was not the important thing. Local corrosion was the trouble which caused nearly all the disasters. If uniform corrosion alone had to be contended with, the difficulty might be met by introducing a factor of safety; it could be allowed for. It was uneven corrosion, pitting and so on, which they could not contend with. For that reason he did not think merely expressing results as a loss of weight per square centimetre, metre, or whatever unit might be chosen, really gave a very accurate indication of what was likely to occur in practice.

Dr. G. H. BAILEY, in reply, said he would endeavour as far as possible to summarize the statement that he thought was due to the members, but he was also anxious to reply to any individual objection which had been taken. Personally he was immensely indebted for the amount of criticism, and especially for any adverse criticism which had been given, because he was present as a seeker after truth, and adverse criticism was the thing which helped towards the realization of that end. He would therefore deal with such points as seemed to him deserving of reply, and would endeavour to be as brief as possible. In the first place, he was glad to be able to array Dr. Bengough on his side, in that at any rate he was cognizant of oxygen as a common cause of corrosion, and he was interested to hear Dr. Bengough's admission that in other metals the same thing might happen. Dr. Seligman rather took exception to his statement of "good and bad tap water." He did not think that would carry any amount of sympathy. Personally, he did not want to specify too clearly as to what the nature of the tap water was—where it came from, and what was its composition. He was afraid that would hardly have done, and those who were business men would agree with him in that statement. All he wished to say was that bad tap water had a greater action upon aluminium than good tap water. Another criticism which had been offered was that he might have overlooked altogether the possibility of other impurities having been carried down on to the metal without being duly allowed for. He was perfectly well aware that that had not been overlooked, and had in fact specifically referred to it in the paper. His experiments had not been directed, as Heyn and Bauer's were, also to solutions of different salts. He had kept the paper as simple as possible, and that was the main part of his policy. Wherever

the tap water was of such a nature that it might possibly and conceivably bring any sediment on to the metal, he had taken the trouble to do what must be done in such cases, namely, follow the impurities up and see whether they came from the metal or from the water. He thought, therefore, it might be taken that the results given were arrived at with every care, at any rate that he could think of. Then he was criticized for not paying sufficient attention to Messrs. Heyn and Bauer's papers, and for quoting certain conclusions that they had already stated. It was not wrong, surely, that he should find himself in agreement with some of their conclusions. It ought to be an honour to them that someone else, working along the same lines, had arrived at the same conclusions, or at any rate some of them. Personally he did not claim any originality for what he had done; he had not taken out a patent for his conclusions.

Those conclusions in several cases were so inevitable that they must be drawn, even though the experiments themselves might not have been conducted on the right lines. The next point was whether solution took place first, and oxidation afterwards. Personally he gave it up; it was an academical point. It might no doubt lead to a valuable discussion on ionization and other things which might take place, but it did not concern him what took place in the first instant during which corrosion occurred. Then he had been ridiculed for the units he had chosen. He selected his unit, as one speaker seemed to imagine he had done, in order to get a unit which should appear not in the second decimal place or the third decimal place, but in order that it should give him some reasonable number. He had a great objection to hybrid units. All his own results were stated in millimetres per 100 centimetres square, and that gave approximately the same number as the one he had adopted. He adopted inches because he thought it might be more useful to people who were engaged in practical work, and having adopted inches he followed suit by adopting grains. With regard to calculating the thickness, he never for a moment wished to suggest that there was $\frac{1}{10}$ inch exactly removed from each part of the field of the surface. He had made it perfectly clear in his paper that he had not tackled anything more than to represent a method by which the amount of aluminium dissolved away from a given sheet should be estimable, independent of all other considerations, which was an important matter commercially. The question as to whether a metal was removed evenly from the surface or by pitting was one that could only be answered by a special investigation devoted to the purpose. He had distinctly stated in his paper that he had not pretended to make that investigation. It was a most interesting investigation, but each case was its own problem. All that he proposed to do was to suggest a method for determining the corrosion of aluminium, and to measure the amount of aluminium removed by different vehicles under different circumstances in a given time, and use that as a measure of the corrosive character of that piece of aluminium according to its composition and properties. Mr. Archbutt thought the times of exposure were too short. Personally he did not think they were—not for a moment. Long ex-

posure, as the members could imagine from what he had said when giving the abstract of his paper, had the disadvantage that all the time the air was being taken out of the water and the aluminium was being protected from attack. Although it might be a problem as to how much aluminium was removed in seven weeks from a given sheet, that was an independent problem. He wanted to get results which could be fairly comparable with one another in analytical practice. He was also aware that the results were in all probability slightly on the high side. Commercially, as he was interested commercially in aluminium, it might be said that that was a mistake. He supposed it was, but he wanted to get a standard on which other people could work, on which the work could be repeated in other hands, and that the results should be capable of being taken together. He was less concerned that he should make aluminium out to be less attacked than it was. Then it was doubted whether 200° was a high enough temperature to get rid of the moisture. As a matter of fact the sheets were heated at that temperature until constant—that was the test; and 200° was a sufficient temperature for removing the water provided sufficient time was given. Professor Turner had asked about the immersion. The immersion was certainly done without supporting on iron or other metal, to which reference had been made in the discussion. These were absolutely fatal to any attempt to determine the corrosion of metal. He found that the simplest and best way in the end was to simply take the sheet, bend it into a half-circle, and put it in the water, resting on the glass vessel at the bottom. He assured the members that not very large numbers of results—of which those given were a condensation—had been made, but he had also made what he had not referred to, immense numbers of confirmatory results, so that it might be taken that the numbers which were given were definite, reliable, and, he thought, sufficient. The fingers were a very effective means for removing any adherent material. He quite admitted that the surface of the aluminium might be changed by the treatment he had suggested, but at the same time something must be done. With a sheet covered with oily and other matter it was necessary to do something. Professor Turner asked what the action would be on the original sheet. The action on the ultimate sheet would depend upon the methods that he used for the cleaning, but it would be very difficult to say what was the action on the original sheet, because it was always covered with a certain amount of impurity which must be removed by the simplest method. With regard to copper, the results which he was obtaining for metal containing copper were not finished at the time he had written the paper.

The PRESIDENT suggested that if Dr. Bailey could communicate any results of that sort, it would be an advantage.

Dr. BAILEY said that he would insert the copper results along with the ultimate data which appeared when the paper was published, but he had already had sufficient general evidence to indicate to him that copper and sodium were accelerating tendencies in regard to corrosion.

COMMUNICATIONS.

Messrs. E. HEYN & O. BAUER (Berlin) wrote that in view of the rather unfriendly form given by Dr. Bailey to his critical remarks on the work published by them on "Phenomena of the Disintegration of Aluminium," they did not wish to enter into a discussion of the work of Dr. Bailey, and would restrict themselves to refuting his unfounded criticism of their work.

(1) It was an erroneous supposition of Dr. Bailey if he thought that the qualities of aluminium examined by them were of a composition which deviated from the commercial quality. They were very much astonished at his assertion, which he himself would find to be a mistaken one if he would occupy himself more closely with the question of aluminium.

(2) If Dr. Bailey desired to reproach them with incompleteness, by having in their experiments made the loss in the weight of aluminium, in consequence of the action of the water, to refer to the weight unit and not to the surface unit, he was again mistaken. The writers did not bring the loss in weight in relation either to the weight or the surface unit, but communicated directly the decreases of weight observed on samples of the same dimensions and, consequently, of the same surfaces. The surface area could be easily calculated from their (Messrs. Heyn & Bauer's) indications, so that anybody who desired to do so could, himself, calculate the losses of weight for the surface unit. They refused to make such calculations as long as it had not been established that the loss in weight, in consequence of the corrosion by water, was proportionate to the surface. They did not believe in such proportionality.

(3) It was a further mistake on the part of Dr. Bailey if he asserted that they had not recognized that the contents of copper and sodium in aluminium might exercise an influence on the amount of corrosion. They knew, of course, that the chemical composition of aluminium was able to exercise an influence on its chemical resistance. On the other hand, they could not understand what that question might have to do with their work. They could only assume that Dr. Bailey had not before him their original work, or that he did not consider it necessary to peruse that work more in detail, before starting to criticize the same. If he had done so he would have observed that the object of their work was to ascertain the origin of the peculiar and local strongly destructive corrosion of aluminium, with which Dr. Bailey did not seem to occupy himself at all.

(4) It was a further mistake on the part of Dr. Bailey if he stated that they had "*assumed*" that, when removing the tarnish on the test plates by means of diluted sulphuric or nitric acid and in the presence of bi-chromate of potassium, the aluminium itself remained without corrosion. They did not assume that, but have proved it, as shown in their Table 6. According to that table there resulted, dependent upon the size of the aluminium samples used and after having subjected the same for ten minutes to the action of sulphuric acid 1:1 with bi-

chromate of potassium, a decrease in weight of the samples by 0.125 milligrammes. The same value was obtained by letting nitric acid (25 per cent.), in addition to bichromate of potassium, act on the said plates for the same duration of time. As the time for removing the tarnish on the aluminium plates did never exceed ten minutes, the mistake caused by the dissolution of aluminium could not exceed the above quantity of 0.125 milligrammes.

Dr. Bailey confined himself to doubting that, but omitted to publish experimental proofs by figures in such a manner that it might be possible to examine these.

The general phrases used by him with respect to that point did not convince the writers of the correctness of his opinion.

Mr. G. CECIL JONES wrote inviting Dr. Bailey to explain why he put forward a formula which was inexact when, by the use of an equally simple formula, the amount of corrosion could be calculated from the experimental results exactly, assuming the accuracy of Dr. Bailey's assumption that the suspended matter was wholly alumina and that no aluminium passed into solution. In many practical cases this assumption would be false, most natural waters depositing calcium carbonate on boiling and acids and alkalies dissolving aluminium. But, even in such cases, the determination of the alumina in solution and suspension was easy, and if its weight were denoted by w and the weight of the plate before and after treatment by W_1 and W_2 respectively, then clearly $W_2 + w - W_1$ was the weight of oxygen which had combined with aluminium to produce alumina, and this oxygen was equivalent to $\frac{9}{8}$ its weight of aluminium, so that the amount of aluminium converted into alumina or dissolved under the conditions of the experiment was given by the formula $\frac{8}{9}(W_2 + w - W_1)$. Applying this formula to Dr. Bailey's worked example, one found that 20.7 milligrammes of aluminium was oxidized. Dr. Bailey's formula led to the conclusion that the corrosion amounted to only 11.7 milligrammes, so that either he (Mr. Jones) had gone astray in his reasoning or Dr. Bailey's formula was not even approximate.

He also invited Dr. Bailey to give some figures in support of his conclusion (No. 2) that, in presence of copper, the corrosion of aluminium was accentuated. He did not wish to be understood as challenging the accuracy of this conclusion, but he had already seen it copied into one daily and one weekly paper, and, in these days of international abstracts, there was a distinct risk that the impression would be widely disseminated that this paper contained evidence on the point, whereas, so far as he could see, it contained none, but merely the author's opinion based on evidence which he had not thought it necessary to bring forward.

Mr. W. B. PARKER (Rugby) wrote that he had read the paper of Dr. Bailey with much interest, and felt it would prove of considerable value, because it quoted all the data necessary to judge the merits of the results stated.

He would suggest that when working with thin, or moderately thin, sheets of commercially refined aluminium, the *total amount of corrosion* produced in a given time by reagents such as water or salt solutions could be more accurately determined by a process based upon a gasometric method, similar to that used for the determination of metallic zinc in a zinc dust containing oxides, than by Dr. Bailey's method.

The following was a rough outline of the method:—

Taking a suitably sized specimen of the metal; clean, dry, and weigh it, and call this weight A.

Then expose it to the corrosion test for the required time.

Remove it from the liquid, washing it very thoroughly (preferably with distilled water), to free it as far as possible from *loose mud*, &c., *but do not rub it*.

Without further treatment ignite or dry the sample in hydrogen at a temperature just sufficient to completely dehydrate the adherent alumina, silica, &c., left on it, and thus render them insoluble in cold or slightly warmed dilute hydrochloric acid; then reweigh the dry sheet, and call this weight B.

Meantime filter off and determine the weight of mud suspended in the reagent used for corrosion. Consider this as being all alumina (Al_2O_3), and call it C.

Now immerse the dry reweighed specimen in dilute hydrochloric acid in a suitable apparatus for measuring the volume of hydrogen given off, and keep it immersed until either all of the metal is dissolved or sufficient to cause the coat of alumina to fall off completely and expose a clean metallic surface. This surface can be washed free from acid subsequently for weighing. The hydrogen is a measure of the metallic aluminium acted upon by the acid, and this is found by calculation—call this D.

If the specimens are very thin sheets, say under 0.032 inch thickness, it will be best to completely dissolve them in the above operation, and thus arrive at the *total weight of metal left uncorroded*.

In this case $A - D$ gives the weight of metal which was corroded.

If the specimen is thick, and thus weighs heavy in ratio to its area, the reaction in the gas apparatus can be stopped as soon as a clean metallic surface is obtained.

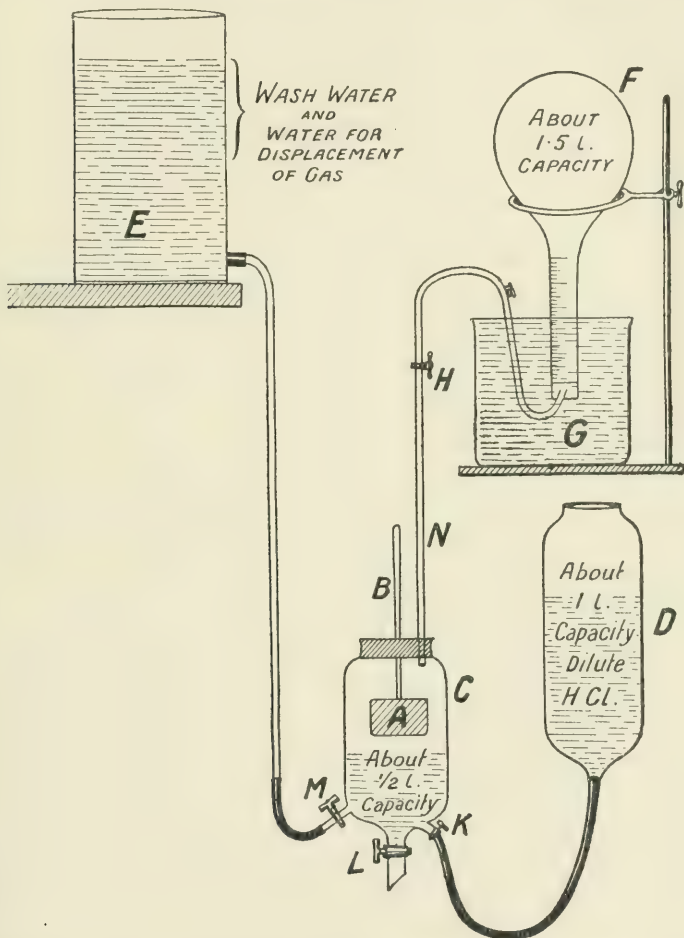
In this case we need to reweigh and determine the aluminium remaining undissolved. This can be done as shown below—suppose it weighs E, and the gas equals D (weight which is dissolved). Then $(E + D)$ = total weight of aluminium not acted upon by the corroding reagent, and hence $A - (E + D)$ = weight of the metal which was corroded.

By subtracting D or $(E + D)$ from B we get the weight of *dry corrosion products* left on the sheet after the corrosion test, and, calling this F, we have $C + F$ = total weight of the corrosion products. This is, however, of less importance and less accurate than the determination of the *unacted upon metal* as given above.

It is easy to measure almost any volume of a gas to 0.1 cubic centimetres. A volume of 1.3 cubic centimetres of hydrogen is equivalent to

0.001 grammes of metallic aluminium. The solubility of hydrogen in water is roughly 2 per cent. by volume of the water at 5°C. , and a correction for this can be made if needful. So this method is accurate to at least ± 0.002 grammes.

The sketch below gives an idea of the apparatus required, and its



method of use. Its size will, of course, depend upon the size of and weight of specimens used, but for a 5 gramme weight is about as below.

The specimen **A** is fixed on an ebonite rod **B**, which passes through rubber bung into the reaction flask **C**. The latter is only about half-full of dilute HCl , *i.e.* to a known volume. The delivery tube **N** is attached,

and the collecting flask with *graduated* neck (F) is filled with water and inverted over the exit of N in trough G. The cock H is opened, and the specimen is pushed down into the acid in C, or the acid in D forced into C, and the gas evolved passes through N and is collected in F. By opening K and raising D enough acid is supplied to vessel C to carry the reaction as far as required. The cock H is then shut, and the pressure of hydrogen in C forces the acid back into D when this is lowered, so that the vessel C is emptied of acid, then K is closed, stop-cock M is opened and also H, and water passes from tank E into C and forces all gas and air into F, where it is measured, and (the volume of air deducted) gives the volume of hydrogen generated. M and H are then shut, A is then withdrawn (if not completely dissolved), washed, dried, and weighed to get E.

Dr. W. ROSENHAIN, F.R.S. (Member of Council), wrote that he was much interested in the question of the corrosion of aluminium and its alloys, and had looked forward to Dr. Bailey's paper with considerable interest. He must confess, however, that he was very disappointed on reading the paper to find that it contained the record of what he could not help regarding as somewhat scanty and unsatisfactory experiments, upon which Dr. Bailey appeared to base a very large superstructure of conclusions, some of which could obviously not be drawn from the data contained in the paper.

With regard to the method of experiment employed by Dr. Bailey, he felt that it was far from satisfactory, principally because the time of immersion was extremely short. His own experiments, extending over corrosion experiments made upon aluminium and its alloys for a period of more than five years led him to the view that the initial rate of corrosion found during the first few weeks of immersion was frequently very different from the average rate taken over months or years. For that reason he felt quite satisfied that experiments made with an immersion of only a few hours were quite untrustworthy as a guide to the permanent behaviour of the material.

The whole question of studying corrosion in light alloys or in pure aluminium, might be approached from two points of view. There was first of all the direct practical point of view from which it was desired to ascertain by experimental means the probable behaviour of a given commercial material in practical use. Now the practical behaviour of such a material must depend on a variety of factors, including the homogeneity of the sheet tested, its condition of annealing, surface condition, mode of support, and finally the composition and constitution of the metal itself. What mattered for practical purposes was the combined effect of all these influences, some of which might be regarded as being fundamental properties of the metal in question, while others would be properly ascribed to imperfections in the mode of manufacture of the sheet. The latter could in many cases be avoided by suitable treatment based upon properly ascertained data, but the fundamental solubility of the metal itself could not be altered except by adopting a different composition. From the other

point of view the question of corrosion was to be studied as a property of the metal itself, and as far as may be the influences of fortuitous conditions of manufacture should be eliminated from the results of the experiments, so that comparative results for metals of different composition could be obtained. Once such results were available, the best material could be decided upon, and its mode of treatment perfected as far as possible afterwards. For the latter purpose, which was that primarily kept in view when systematic investigations of alloys were carried out, the method of making corrosion tests by ascertaining the loss of weight appeared to be a sound one, since it rightly disregarded from this point of view the locally destructive effects of pitting, and merely measured the general average solubility of the metal. On the other hand, as a practical test, determinations of the loss of weight were not satisfactory unless they were accompanied by evidence as to the absence or presence of pitting; but it was not easy to devise any quantitative method of recording observations on pitting, and a mere ocular estimate was not very satisfactory for comparison purposes between a number of somewhat similar materials. Perhaps the best method to use would be to employ comparatively thin sheets, and to note the order in time in which the sheets of various materials were completely perforated, or as an alternative series of specimens of the same material might be exposed to the corrosive influence and subjected to mechanical tests at specified intervals, the mechanical tests (tension) serving as a rough means of measuring the least cross sectional area of the strip. Of course with such very short periods of immersion as those employed by Dr. Bailey, the question of pitting hardly arose at all, but he could not regard those tests seriously as giving any real information on the subject.

Dr. R. SELIGMAN (London) wrote that, in replying to the verbal discussion of his paper, Dr. Bailey gave the following two reasons for not stating in his paper that his conclusions 4, 5, and 6 were arrived at several years ago by Heyn and Bauer, namely:—1. That these authors gave their results as percentage loss of weight. 2. That their determinations were inaccurate owing to certain errors in arriving at the loss of weight.

With regard to the first statement, he (Dr. Seligman) could only assume that Dr. Bailey was relying on an imperfect abstract. Had he consulted the original, he could not have failed to observe that the samples with which Messrs. Heyn and Bauer worked were all cut to a uniform size. Their results were, therefore, strictly comparable with one another. Moreover, they gave the exact dimensions of their test-pieces, even to the thickness, so that their results were also comparable with those of other workers.

As to Dr. Bailey's second statement, he would remind Dr. Bailey that the chief value of the paper of Heyn and Bauer lay not in their gravimetric results, but in their observations of the different forms which corrosion assumed under the varying conditions of their experiments and with the various forms of metal which they used.

Mr. H. J. YOUNG (Wallsend-on-Tyne) wrote that at one time he had experience of the making of corrosion tests, and his observations were that if a sheet of metal were placed for a definite length of time in a liquid, the results were anything but accurate, the main sources of inaccuracy arising from the following factors:

1. The molecular condition of the surface of the metal.
2. The bulk of liquid employed and the means whereby its constitution was kept constant (occasional filling up with water being ineffective).
3. The small variations in pressure made large differences in dissolution.
4. The uncertain quantity of agitation.
5. The unknown quantity of air introduced during the experiment (partly by 4).

The first difficulty was only solved by using fine wires drawn through the same die, even though unlimited supplies of sheets were available; while the other four were overcome by the invention of an apparatus specially designed to meet the case. Without those innovations, he (Mr. Young) would be inclined to regard the results with respectful caution.

Dr. BAILEY wrote in reply to Mr. Jones that the latter's statement, "then clearly $W_2 + w - W_1$, was the weight of the oxygen which had combined with the aluminium" was incorrect; the expression really represented the weight of the oxygen in the suspended and detachable alumina, *plus* the weight of the adherent alumina. With regard to Mr. Parker's proposed method, tempting as it might appear, he (Dr. Bailey) had found it to fail principally in consequence of the errors arising from the presence of iron and silicon in the metal.

Dr. Rosenhain seemed disappointed that the subject of the paper was something quite different from what he had anticipated, though the purpose of the author had been very distinctly indicated both in the paper itself and during the verbal discussion. Yet he thought no one was in a better position than Dr. Rosenhain himself to realize that the problems in his (Dr. Rosenhain's) mind must, owing to their complexity, be attacked by special methods, and would involve years of work. The author had laid down as a necessary preliminary to all such inquiry a departure from the slipshod methods of determining the amount of aluminium removed from a given sample under observation, and he believed that some such departure was essential to further progress in research on whatever lines it might proceed.

He proposed, with regard to Messrs. Heyn & Bauer's communication, to follow the order of their own statements.

1. As to the composition of the samples of aluminium used by Messrs. Heyn & Bauer, he found that out of a large number of samples only three seemed to have been analyzed at all completely, the percentage impurity being given as follows:—

Silicon.	Iron.	Copper.
Per Cent.	Per Cent.	Per Cent.
0·86	0·52	0·02
0·70	0·53	0·03
0·67	0·50	0·03

It was clear therefore that, disregarding minor constituents, the impurities in those samples could not have been less than 1·29 per cent. on the average. In those samples where the content of silicon alone was quoted, it was noteworthy that that was very high, and thus the metal must have been of low grade; it was also singular that each of the three samples contained copper (an unusual constituent), the copper in the rest not having been estimated. It thus became evident that if Messrs. Heyn & Bauer's statement were to be accepted, the metal contained at least double the impurity usual in the case of aluminium made in the British Isles, and, as the author was aware, in many other quarters. Sodium, always present, and often in quantities such as to have a serious affect on the behaviour of the metal towards reagents, was not even mentioned, though nitrogen to the extent of about one-thousandth per cent. was not overlooked.

2. The statement as to the necessity for associating the amount of corrosion with surface rather than with the weight of metal, was not made in reference to Messrs. Heyn & Bauer's work, in which manifestly the proper course had been adopted in that respect.

3. It was quite recognized that the objects which Messrs. Heyn and Bauer had in view were different from those taken up by the writer, but so far as the analytical methods and details were concerned, these could not fail to be of interest as indicating that the specific precautions mentioned were necessary and important in view of the conclusions based upon the results. Yet it seemed strange that if it were known that copper and sodium had an important effect, especially on disintegration, the presence or absence of those elements should have been practically left out of account. It was also remarkable that, and especially in view of the subsequent behaviour of aluminium as related in Messrs. Heyn & Bauer's paper, the 230 cubic centimetres of water used was, so far as could be gathered, not renewed or aerated during 207 days exposure.

4. With regard to the conflict of testimony as to the possibility of completely removing a coating of alumina without acting materially upon the metal, the assurance could only be made that the perfectly definite statement given in the author's paper would not have appeared unless he had assured himself by numerous observations that it was justified. He had, as indicated, approached the matter from more than one standpoint, and he now felt that it need not be unduly laboured, as Messrs. Heyn & Bauer were in a position to satisfy themselves on the point by experiment, and from an examination of their own published results. These showed very considerable variations on duplicate speci-

mens ; they showed in a large number of cases, even on similar specimens, *positive* and *negative* values widely differing. No further proof than that was necessary to indicate that the method was untrustworthy.

In conclusion, the author wished to make it clear, in reply to more than one of those who had spoken upon the paper, that according to his experience it would be better to trust in general to a short, but not too short, period of exposure to the reagent ; that would vary with water and salt solutions from a day to a week according to circumstances. In special cases a prolonged exposure might be essential, but in such cases (as had been illustrated in the paper) wide variations were possible, and only specific conclusions could be drawn from the results. It was also material to add that the numbers quoted in the paper were representative of a very numerous series of experiments, which it would have been impracticable and useless to reproduce in full, and that wherever possible or necessary parallel duplicate determinations were performed in confirmation of the values accepted.

THE MICROSTRUCTURE OF GERMAN SILVER.*

BY O. F. HUDSON, M.Sc., A.R.C.Sc.
(BIRMINGHAM UNIVERSITY).

THE white and ductile alloys of copper, nickel, and zinc which are known as "German Silvers" are of somewhat widely varying composition, and are made in a number of different qualities, the most usual of which contain about 55–60 per cent. of copper, 15–20 per cent. of nickel, and 20–30 per cent. of zinc. The general properties and microstructure of this class of alloys are described by Law,[†] who points out that, like almost all commercial ductile alloys that are rolled and drawn, they consist essentially of crystals of one substance only, namely, a solid solution. Also he has shown that the microstructure of German silver closely resembles that of the brasses which consist of the α solid solution of the copper-zinc series, and these observations are in agreement with the results of Tafel's[‡] investigation of the ternary system copper-nickel-zinc.

In order to study the effect of continued annealing on the crystalline structure of German silver a number of samples were supplied to the author by Mr. G. A. Boeddicker. These samples were all of the same quality and of the following approximate composition:—

	Per Cent.
Copper	58.0
Nickel	18.5
Zinc	23.5

The samples had been annealed under ordinary works conditions at a temperature of 700°C. for varying lengths of time. Two series were supplied, the first having annealing times of 1 to 10 hours and second from 24 to 72 hours.

* Read at Annual General Meeting, London, March 12, 1913.

† "Alloys and their Industrial Applications," by E. F. Law (Griffin).

‡ V. E. Tafel, *Metallurgie*, July 1908, vol. v. p. 413.

Typical microstructures* of the cold-rolled and annealed samples are shown in Plate III. Figs. 1 to 6. These show that the usual crystalline growth takes place on annealing, but it will also be observed that the cold-rolled alloy still shows very distinct signs of the original cored structure of the cast material. The "cored" structure is still in evidence after prolonged annealing, as is shown by Fig. 5, which is the microstructure of the sample after 48 hours' annealing at 700°C . After 72 hours' annealing at 700°C . the alloy is practically homogeneous (Fig. 6), although faint traces of the "cores" were observed even in this sample when very slightly out of focus under the microscope. The conclusion that the light and dark shading observed on the etched surfaces of Mr. Boeddicker's specimens was due to the persistence of the original "cores" of the crystals of the cast alloy was confirmed by experiments with an alloy of similar composition cast in the laboratory. The alloy was cast in a small strip mould, and the casting, $\frac{7}{32}$ -inch thick, was rolled, annealed by heating to about 700°C . for a few minutes, and rolled again to give a strip $\frac{1}{8}$ -inch thick. The structures of the cast alloy and the final cold-rolled strip are illustrated in Plate IV. Figs. 7 and 8. Portions of the cold-rolled strip were then annealed for varying times at a temperature of 720°C ., and typical structures of annealed specimens are shown in Plate IV. Figs. 9 and 10. Here again the persistence of the "cored" structure is evident. Fig. 9 shows that annealing at 720°C . for 6 hours was quite insufficient to give uniformity of composition, but after 15 hours at this temperature (Fig. 10) the alloy was perfectly homogeneous. The question of whether or not a German silver is composed of a perfectly homogeneous solid solution can be decided by the examination of a suitably polished and etched surface by means of a hand lens, or even by the naked eye; for the presence of any remains of "cores" is shown by a very fine but distinct

* The specimens for microscopic examination were prepared as follows: The surfaces were filed and rubbed on emery-papers in the usual way, then lightly polished with "Globe" metal polish, and finally rubbed on wet parchment on which was spread some freshly prepared magnesia. The specimens were then dipped in a strongly acid solution of ferric chloride for a few seconds, lightly polished with magnesia, and again treated with ferric chloride, these operations being repeated if necessary.

pattern or graining which is accentuated by relief polishing, owing no doubt to slight differences in hardness.

The extreme slowness of diffusion in German silver as compared with the corresponding *a* solid solution of the copper-zinc alloys is caused by the presence of the nickel. Diffusion appears to take place equally slowly in cupro-nickel, as is shown in a series of photomicrographs of the structure of that alloy which were published by Bengough in his recent paper on the properties of alloys at high temperatures.* An examination of those photographs indicates that annealing for an hour at a temperature of 800° C. was insufficient, and that the same time at 900° C. was required to make the alloy homogeneous.

It may be of interest very briefly to note here the results of a few preliminary experiments made to determine the effect of heat treatment on the properties of German silver.

Rolling Qualities.—Annealing for 10 minutes, 100 minutes, and 10 hours at 800°, 850°, and 900° C. in all cases gave specimens that were found to roll easily and well, and the same result was obtained after annealing for half an hour at 950° C. and 1000° C. All these annealings were carried out in air in an electrically-heated tube furnace, while a specimen annealed for 2 hours in an atmosphere of coal-gas at 850° C. also rolled perfectly. A portion of the specimen whose structure is shown in Fig. 10 was also rolled with satisfactory results, and on again annealing for a short time at 750° C. the structure of the alloy was, as shown in Plate IV. Fig. 12, one that indicates no deterioration in mechanical properties. It thus appears that a coarse crystalline structure due to prolonged or drastic annealing is in itself no sign of inferior rolling qualities.

Hardness.—The original series of specimens supplied by Mr. Boeddicker were tested by means of the Shore scleroscope, and the results, of which a selection is given, show that prolonged annealing accompanied by pronounced crystal growth does not lead to any decrease in hardness beyond that due to the normal annealing operation.

* *Journal of the Institute of Metals*, 1912, No. 1, pp. 123-174, Plate XV. Figs. 2 to 6.

		Hardness Number.*
As rolled	.	60
Annealed for 1 hour at 700° C.	.	23
" 3	" "	23
" 10	" "	26
" 48	" "	23
" 72	" "	26

In conclusion the author wishes to thank Mr. G. A. Boedicker for his kindness in providing the material on which this work has been carried out.

* The hardness number is that obtained with the "Blunt" hammer.

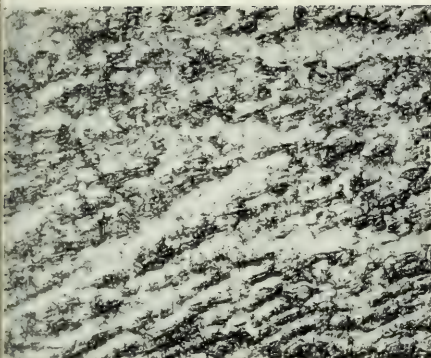


FIG. 1.—As Rolled.

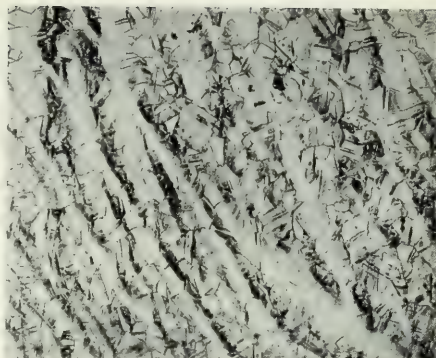


FIG. 2.—Annealed for 1 hour at 700° C.

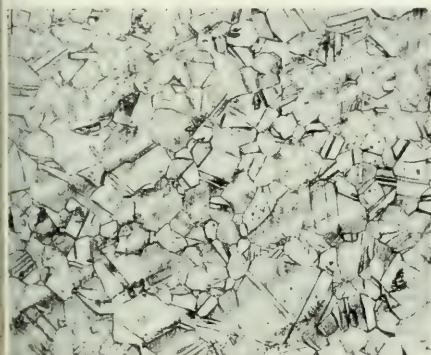


FIG. 3.—Annealed for 10 hours at 700° C.

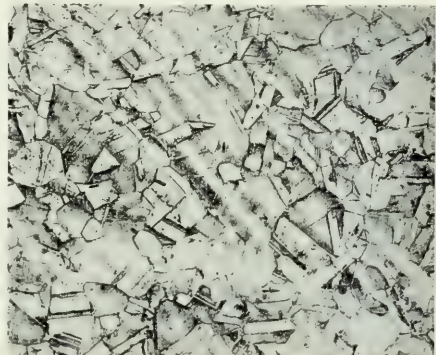


FIG. 4.—Annealed for 24 hours at 700° C.

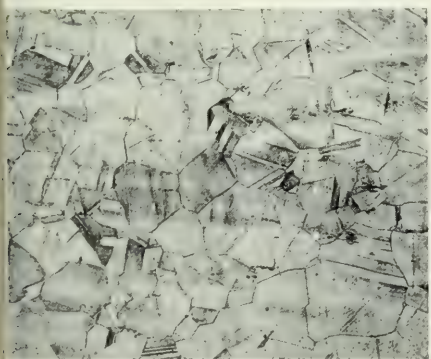


FIG. 5.—Annealed for 48 hours at 700° C.

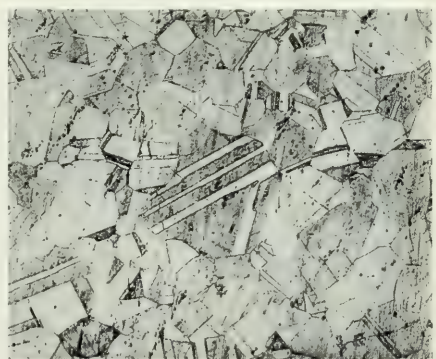


FIG. 6.—Annealed for 72 hours at 700° C.

Photographs illustrating the effect of annealing at 700° C. on the structure of German Silver containing copper, 58 per cent. ; nickel, 18·5 per cent. ; zinc, 23·5 per cent.

In all cases—Magnification 100 (reduced 20 per cent. in reproduction); illumination vertical; etching medium strong ferric chloride.



FIG. 7.—Cast.

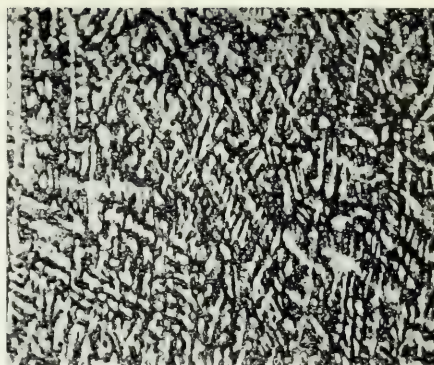


FIG. 8.—Cold Rolled.

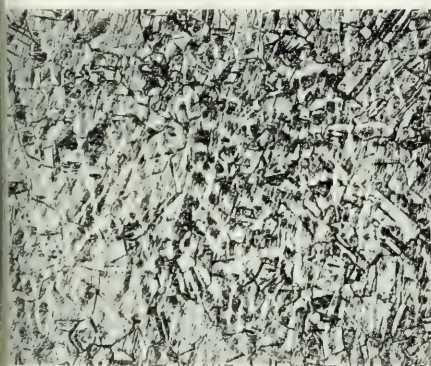


FIG. 9.—Rolled and Annealed for 6 hours at 720° C.

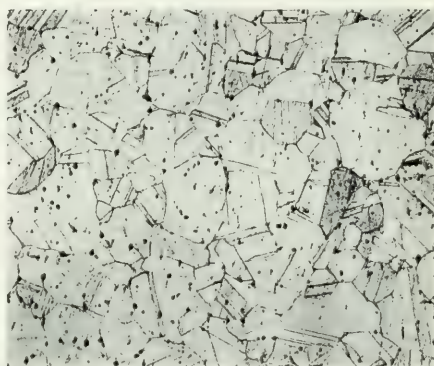


FIG. 10.—Rolled and Annealed for 15 hours at 720° C.

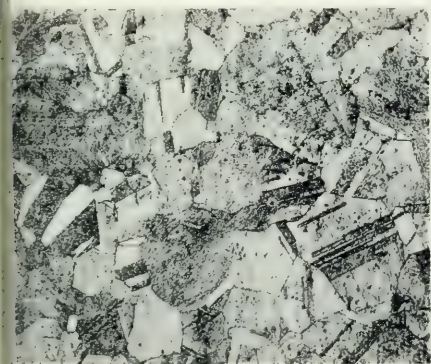


FIG. 11.—Same as Fig. 10—Cold Rolled.

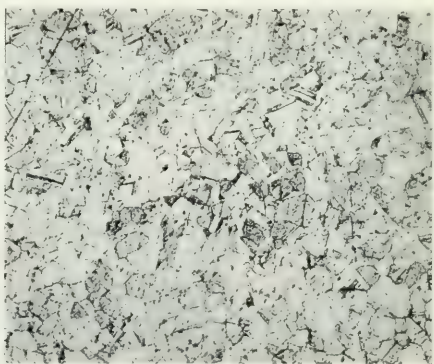


FIG. 12.—Same as Fig. 11—Annealed at 750° C.

Photographs of the structure of German Silver containing about 58 per cent. of copper, 18 per cent. of nickel, and 24 per cent. of zinc.

In all cases—Magnification 100 (reduced 20 per cent. in reproduction); illumination vertical; etching medium strong ferric chloride.

DISCUSSION.

Mr. G. A. BOEDDICKER (Member of Council), in opening the discussion, congratulated the author on having first drawn attention to the peculiarity of the addition of nickel to alpha brasses retarding diffusion or recrystallization. The results given on page 112 of the softness in connection with the different times of annealing bore out the results obtained in ordinary practice. Annealing from 20 minutes to an hour was perfectly sufficient to render the German silver soft enough for all purposes. A higher temperature for a shorter time would undoubtedly be useful, and was frequently employed where it was a question of thin sheets. Where, however, it was a question of a sheet of say $\frac{1}{2}$ -inch to $\frac{3}{4}$ -inch thick, a short time at a high temperature was impossible, and a longer time at a lower temperature was necessary to affect the metal evenly all through. The test of softness applied to one thing only, namely, if the metal could be rolled or stamped. Whether the metal annealed for a long time, though quite soft, would stand other mechanical tests, such as were absolutely necessary at the present time, was to him very doubtful. He should say that a metal like that shown in Plate III. Fig. 6, which had been annealed for 72 hours, with a very large increase in the size of crystal, would not stand the same work as Fig. 2. He was exceedingly pleased that German silver was coming to the front at present for scientific research. Since the price of tin had gone up so enormously, German silver was frequently used in place of Britannia metal, and, whereas formerly German silver was hardly used in any other way than for stamping or raising, manufacturers had begun to work it similarly to Britannia metal by spinning and pressing. It was exceedingly difficult to get any German silver to stand those very severe demands, and a great many more experiments were necessary. German silver could not be simply treated in two lines by calling it an "alpha brass where part of the copper has been replaced by nickel." The percentage of nickel to start with was very variable, varying from 7 to 30 per cent., and the effect of the nickel was very great not only in colouring, but also in raising the resistance. A 7 per cent. German silver had a resistance of 18 microhms, and 30 per cent. German silver had a resistance of 40 microhms; in fact, between those limits the addition of every 1 per cent. of nickel practically raised the resistance by 1 microhm. That was so near that it was possible to determine beforehand what alloy to make in order to get a certain resistance. The percentage of zinc in the alloys seemed to be of very little importance. Another point of very great interest would be to determine the resistance in the different specimens after different amounts of annealing. After an ordinary annealing lasting one hour at 700 degrees, he found the resistance went down about 2 microhms, and he thought that, by annealing it until perfect diffusion had taken place, the resistance would very likely go down a few more microhms. There was one further point which, although it did not really belong to the paper, he would like to mention—namely, some peculiarities

of cobalt, which was a very similar metal to nickel, only whiter, and which had lately come into more general use as an addition to cobalt steel. They did manufacture metallic cobalt, but hitherto the demand had been exceedingly small—perhaps 5 to 10 cwts. a year, but the increased demand gave him an opportunity of testing a few cobalt copper alloys. He found, first of all, that, though cobalt was so much whiter than nickel, it had practically no colouring effect on copper alloys. While an 80–20 per cent. copper nickel was perfectly white, an 80–20 per cent. copper cobalt was almost as red as copper. And further, while nickel had a very strong effect, as he said before, in raising the resistance, cobalt had hardly any effect at all; for instance 80–20 per cent. copper nickel had a resistance of 28 microhms, while an 80–20 per cent. copper cobalt had a resistance of only 10 microhms.

Dr. T. K. ROSE (London) said that the paper was a piece of work of a kind very well worth doing, and that it had been very well done. There were one or two points in it to which he desired to draw attention, because they had raised difficulties in his mind, and he wished the author to resolve those difficulties for him. For example, he had no doubt that the particular alloy referred to was one in which cores actually did occur, but he was not sure that he understood what the author meant by cores. His own idea of a core was an onion-like structure in which every layer was of a slightly different composition from every other layer. Looking at the photographs on Plate III., there was no evidence at all of the existence of cores in this sense. The appearances, taking them from Fig. 2 onwards, were producible by treating in a similar kind of way the very purest gold that could be obtained, and there he thought everyone would admit there was no question of cores. The question had the importance to him that the author seemed to think it necessary to assume (*e.g.* near the top of p. 111), that in annealing there was diffusion of a metal into the neighbouring region so as to make the alloy of uniform chemical composition. He did not believe that the recrystallization, such as the author showed in Figs. 2 to 6 of Plate III., had anything to do with diffusion, but that it was entirely a question of a change in the orientation of the particles. Consequently, he did not want that case to go entirely by default, and it was for that reason that he mentioned it. The author said on page 111 that by annealing for ten minutes at 800°, and by annealing for half an hour at 1000°, exactly the same result was obtained. That, in his opinion, proved without actual trial that all the other intermediate results were correct.

With regard to the question of the rolling qualities of metals, Professor Huntington had asked him last September if, as the result of his observations, he could express any opinion on the following point. Were the rolling qualities of an annealed metal, consisting of ragged crystals set as it were in a sort of matrix, different from those of the same metal after further annealing, by which the irregular polygonal structure had been set up? He had been obliged at that time to say that he was studying the matter, and did not know. However, he was able to answer

the question at the present moment, by saying that he was absolutely in accordance with the author in the last sentence in the "Rolling Qualities" paragraph of the paper, page 111, where he said, "It thus appears that a coarse crystalline structure due to prolonged or drastic annealing is in itself no sign of inferior rolling qualities." He (Dr. Rose) would add that it was no sign of superior rolling qualities. He could find no difference at all any more than Mr. Hudson could. He did not wish to go into the question of hardness except to say that he maintained the position he took up last September, although he was not prepared at the moment to prove it. He hoped to be able to carry conviction in his arguments where last September he only obtained a certain amount of qualified acquiescence, and consequently he did not accept what the author said in his paper, although he did not question the approximate accuracy of the hardness tests.

The PRESIDENT inquired on what point Dr. Rose differed from the author.

Dr. ROSE replied that he differed from the author in the statement that prolonged annealing accompanied by pronounced crystal growth did not lead to any decrease in hardness beyond that due to the normal annealing operation.

The PRESIDENT asked Dr. Rose if he proposed to read a paper on the point.

Dr. ROSE said that he intended to deal with the matter in the course of a future paper. Meanwhile, he did not want that point to go by default either. As for the main thesis of the paper, manufacturers ought to want to know, if they wanted to know anything about the question at all, whether their practice was the best possible practice; they wanted to know the minimum time and temperature required for annealing, and the author had not drawn precise conclusions on those points. Nevertheless the value of the work was obvious to all, and he agreed that the Institute ought to be very grateful to the author for having brought the paper forward.

Mr. G. B. BROOK (Sheffield) asked whether the German silver dealt with in the paper was prepared from ordinary metal or from perfectly pure metals. He also wished to know in Plate IV. Fig. 10 particularly what the dark constituent was—the small spots. Was it a segregation of lead, because it nearly always appeared on samples of German silver of commercial manufacture. He would like to know whether it was prepared with metals of known purity, so as to eliminate the possibility of lead segregating out in that particular way.

Mr. E. F. LAW (London) said he wished to congratulate the author on his paper and also on the photographs, which were really

excellent in every way. The peculiar persistence of cores referred to was not confined to German silver. He did not know whether the author had noticed it, but it occurred in the so-called γ -steels—steels containing nickel and manganese in fairly high percentages. In these it was usually missed, because the ordinary etching methods did not show it up; but if the steels were heat-tinted the cores were shown very distinctly. German silver was not the only metal evidently in which it occurred. That was the only point he wished to refer to in the paper itself, beyond making one request. He was sorely tempted to digress from the author's paper to Mr. Boeddicker's remarks, but he thought that was hardly allowable in the discussion; but he hoped the President, after the meeting, would talk very seriously to Mr. Boeddicker, and quietly but firmly insist on receiving a paper from him on the subject of German silver.

Professor T. TURNER, M.Sc. (Honorary Treasurer and Vice-President), agreed with Dr. Rose that the author might with advantage have amplified the paper. Mr. Hudson had very briefly given the result of a good deal of work. Some of those present had the opportunity in the Birmingham Section a short time ago of hearing, in the form of a preliminary canter, some of the matter dealt with in the paper; but the paper was then four times as long as it was at present. If the author had given in his present paper all the particulars that some of the members had heard before at Birmingham, he did not think there would have been any need for criticism. The author was afraid, he supposed, of going into too much detail for the Journal, and possibly he had erred on the other side. With regard to the question of coring, he could see evidence of coring in the photomicrographs; but the reason for that probably was because he had seen the original samples, and the author had pointed out the structure to him, and, having seen the samples, he could now see it very plainly in the photographs. It might be that Dr. Rose, not having seen the original samples, did not see the dark areas—the smudges, so to speak, on the microphotographs which were indications of the continuance of the original cores.

Mr. E. L. RHEAD, M.Sc.Tech. (Manchester), said that he had observed something very much akin to the appearances that were present on the photographs in the case of pure electrolytically deposited copper; and in that respect he would like to confirm Dr. Rose's opinion in regard to pure metals.

Professor A. K. HUNTINGTON, Assoc.R.S.M. (President), said that in his Presidential Address he gave an example of a core structure of copper-zinc alloy, and he would like to ask the author whether he had ever made any comparison of the temperature required to eliminate the cores in the two cases. The author's cores did not come up so strongly as shown in his (the President's) photograph. Personally, he had never, that he could remember, attempted to get them up in that kind of material, and he was wondering whether they came up normally very

strongly. To some extent it was a question of the way the metal was cast. He noticed that there were a lot of specks all over photograph No. 10, and he would like to know what they were. The author spoke of etching and then polishing, and he took it that the structure was developed mainly in relief.

Mr. O. F. HUDSON, in reply, said he was sorry to find that some members considered the paper to be too brief. The first part of the paper was the one that he particularly wanted to bring before them; the other part simply contained the results of a few preliminary experiments on the effect of annealing on different qualities of the metal. He could not say whether it would be of any use to manufacturers; but it appeared to him that if it was shown that an alloy could be annealed at almost any temperature and for any time, and that reasonably good results were still obtained, that should be a certain amount of use to those who were dealing with this alloy. Mr. Boeddicker made some very kind remarks about the paper. With regard to the resistance of the material, he himself had not done any experiments on the point, so that he could not add anything to what had been already said. Annealing at higher temperatures, and the possibility of the loss of zinc taking place under those conditions, might be a serious matter in a manufacturing operation. Dr. Rose had referred to the cores. He understood Dr. Rose did not really believe that they were cores. It was partly for that reason that he (the author) introduced the figures 7, 8, 9, and 10 on Plate IV. He had no doubt that Fig. 7 was the ordinary core structure of the cast material. Fig. 8 showed equally well the same type of structure and Fig. 9 the same, and then the coring gradually disappeared. It appeared to him that that very strongly confirmed the idea that the markings on the commercial sample of German silver were simply due to such cores resulting from slight differences in composition in different parts of the same crystal.

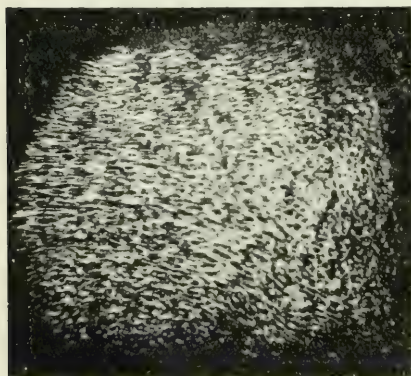
Mr. BOEDDECKER said he presumed Mr. Hudson meant chemical composition.

Mr. HUDSON replied in the affirmative. He rather thought they agreed on the point of diffusion and recrystallization. Recrystallization took place regardless of any diffusion that also took place at the same time. He thought the photographs showed that quite clearly. With regard to the hardness of the specimens under prolonged annealing, he was afraid he could only say that the results given were those which he obtained, and that, so far as he could tell from the figures, the hardness as measured in the scleroscope was no lower with a coarse crystalline structure after seventy-two hours than it was with a comparatively fine one after one hour. A question was asked as to the nature of the small black spots shown so clearly in Plate IV. Fig. 10. If the photographs were carefully looked at they would be seen in some of the other photographs too. He considered they were due to the presence of small particles of lead. The

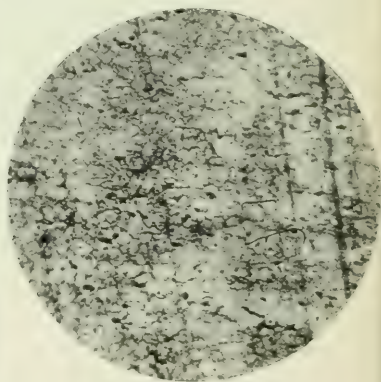
alloy was made up with good commercial material. He was not quite sure whether the small amount of lead so introduced would account for all those black spots, but he came to the conclusion that they were due to small particles of lead present in the alloy. The President had referred to the question of whether the cores shown were developed normally. They were, but the etching method which he described briefly on page 110 showed the coring very much more distinctly. That was a combination of slight polishing with the etching.

COMMUNICATIONS.

Mr. H. GARLAND (Cairo) wrote that he was very pleased to read Mr. Hudson's remarks (page 110) on the persistence of the "cast-cored" structure of that alloy after annealing, because it was a conclusion to which he was forced some time ago in connection with investigations he was then making on ancient Egyptian bronzes. He (Mr. Garland) found, on polishing sections of old bronze knives, chisels, &c., about 3500 years old, that in most instances he obtained a core structure (showing all the usual strains



Result of cold hammering, showing core structure.
Magnified 18 diameters.



Shows same section, deeply etched.
Magnified 270 diameters.

FIGS. 1 and 2.—Section of Egyptian Copper Knife Blade, about 3000 years old.
(Etched with ammonium persulphate 10 per cent. solution.)

and deformation due to cold hammering), which was more or less apparent on simple polishing because of differences in the hardness of the phases. But, according to the present accepted theory, during the extended lifetime of those articles, recrystallization should have taken place at atmospheric temperatures. Upon deep etching this was found to be the case. The cores and the surrounding phase were found to be made up of very small crystal grains (just visible with a magnification of 60), and it seemed to him that a gradual annealing effect had taken place, but

the new grains did not appear to have grown, as generally happened in practice upon prolonged heating at the temperatures usually adopted for annealing processes. He, therefore, concluded that in the case of cold-worked metals, recrystallization took place at normal temperatures if sufficient time were allowed (as stated by Dr. T. Kirke Rose), but that diffusion did not occur at those temperatures, the cores and matrix simply breaking up, *in situ*, into small crystal grains (thus relieving the internal strains), and remaining in the same condition, physically and chemically, afterwards. He deduced from this, that to bring about diffusion in an alloy of that type a more or less elevated temperature was absolutely essential. He was keeping these facts for a paper which he hoped to present later, but as Mr. Hudson had brought up the question it would probably be of interest to him to hear them now, and he would be glad to have Mr. Hudson's comments.

Mr. F. JOHNSON, M.Sc. (Birmingham), wrote that he was greatly interested in the micrographic results in the author's paper, which brought out so strikingly the extreme slowness of diffusion in German silver. He had had occasion to notice a similar sluggishness, in the case of commercial 9-carat alloys, also in the case of an experimental copper-arsenic alloy (2 per cent. arsenic) and even of a commercial copper-arsenic alloy (4 per cent. arsenic). Although, in these cases, the sluggishness of diffusion was not comparable with that of Mr. Hudson's alloys, yet the same phenomena presented themselves, after annealing of a duration more than sufficient to completely soften the alloys, as occurred in the case of German silver and cupro-nickel.

Mr. HUDSON, in reply, thanked Messrs. Garland and Johnson for their communications. Mr. Garland's observations on the structure of ancient bronze implements were of great interest as affording a further instance of recrystallization in metals and alloys apparently quite independent of any chemical diffusion. He agreed with Mr. Garland that in the bronzes mentioned a temperature much above the normal would be necessary to cause any appreciable diffusion. He was glad to notice that Mr. Johnson had observed in other alloys a behaviour similar to that which he (Mr. Hudson) had observed in the case of German silver.

THE QUANTITATIVE EFFECT OF RAPID COOLING UPON THE CONSTITUTION OF BINARY ALLOYS.*

By G. H. GULLIVER, B.Sc., F.R.S.E., A.M.I.MECH.E.

I. INTRODUCTION.

THE physical properties of an alloy which has solidified quickly may differ greatly from those of the same alloy allowed to crystallize slowly. The differences produced by varying the rate of cooling during the freezing period are correlative with a twofold variation in the structure of the alloy, namely, a change in the dimensions of the crystal aggregates, and a change in the constitution of the mixture. The exact effects to be ascribed to each change separately are not yet known, but in general an alteration of constitution is more important than one of crystal size. The relation between the rate of cooling and the structural arrangement of an alloy has been determined only in the roughest manner on account of the difficulty, when the rate of cooling is not very slow, of specifying what the rate actually is at any point of the mass of metal. The equilibrium diagram for a series of alloys shows the constitution of each particular mixture when the rate of cooling is excessively slow, but it gives one only a rough idea of the constitution of more quickly cooled mixtures. On the other hand, as will be shown herein, it contains the data from which the constitution of mixtures cooled with excessive rapidity may be calculated, if certain assumptions are made, so that the limits within which the constitution of a particular alloy can vary, for extreme values of the rate of cooling, may be regarded as known when the equilibrium diagram for the series has been determined.

In a simple type of alloy of two metals each solid component is capable of holding in solution a certain limited proportion of the other, and the two solid solutions when

* Read at Annual General Meeting, London, March 12, 1913.

present together form an eutectic. The diagram illustrating the physico-chemical conditions of equilibrium of the series is of the form of Fig. 1, where temperatures are represented by ordinates, and the composition of the alloys, in percentages of the two components *A* and *B*, by abscissæ. The broken line *CED* is the liquidus or freezing-point curve—that is, the locus of the temperatures at which the various molten alloys of the

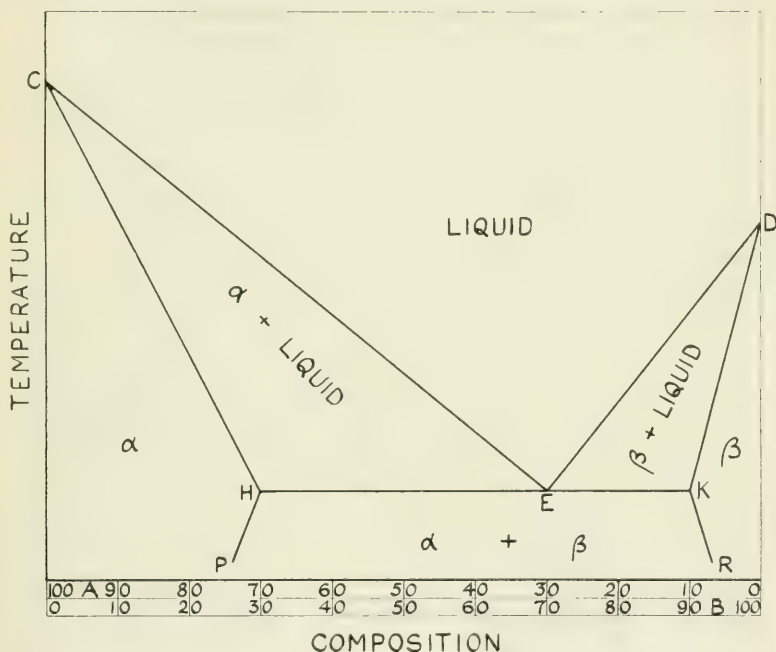


FIG. 1.—Typical Equilibrium Diagram for a series of alloys in which the structural constituents are two solid solutions, α and β , and an eutectic, *E*.

series begin to solidify when cooled; a point above *CED* represents a mixture which is wholly liquid, while one immediately below the line represents a mixture which is partly liquid and partly solid. The broken line *CHKD* is the solidus or melting-point curve—that is, the locus of the temperatures at which the various solid alloys begin to liquefy when heated; a point below *CHKD* represents a mixture which is wholly solid, while one immediately above the line

represents a mixture which is partly solid and partly liquid. The points H and K represent respectively the limiting composition of the solid solution of B in A , and the limiting composition of the solid solution of A in B ; of the first of these solutions, called α , the metal A constitutes the greater portion, while in the second, called β , B is in excess of A . The lines PH and RK represent the changes in the limiting compositions of the solutions α and β at temperatures below HK . The point E , at which the two branches of the liquidus intersect, represents the eutectic alloy of the series.

The equilibrium diagram, Fig. 1, is divided by the various lines into a number of fields, each having a distinct signification. A point in the triangular space CEH , included between the liquidus and solidus, indicates a mixture which is partly liquid and partly solid; the solid portion contains more of A and less of B than the liquid portion, and consists of crystals of the α -solution having a composition which varies with the temperature. Similarly a point within the triangular area DEK represents a mixture of β -crystals and liquid. An alloy of which the composition lies to the left of H solidifies completely at a temperature above HK to a mass of homogeneous α -crystals; one with a composition represented by a point to the right of K also becomes completely solid above HK , and consists of homogeneous β -crystals. An alloy having a composition between H and E , when the temperature just reaches HK , is formed of saturated α -crystals of composition H and liquid of composition E ; the liquid solidifies at the constant temperature of the line HK as the eutectic mixture of the series, a conglomerate of tiny crystals of the saturated α - and β -solutions. When the composition of the alloy lies between E and K , the β -crystals first formed reach the saturation composition K , and the rest of the mass solidifies as the eutectic E . Thus all alloys between H and K contain both α - and β -crystals.

The earlier products of solidification are frequently termed primary crystals in order to distinguish them from the secondary eutectic or other crystallization. The manner in which the composition of a primary crystal changes during the period of its formation is important, and has been carefully described

by Roozeboom.* Consider the case of an alloy X , Fig. 2, containing a less proportion of the metal B than is necessary to saturate the α -solution at the eutectic temperature. Draw a vertical line—that is, one of constant composition—through X , cutting the liquidus at x' and the solidus at x''' . When the liquid alloy is cooled, x' is the temperature at which it

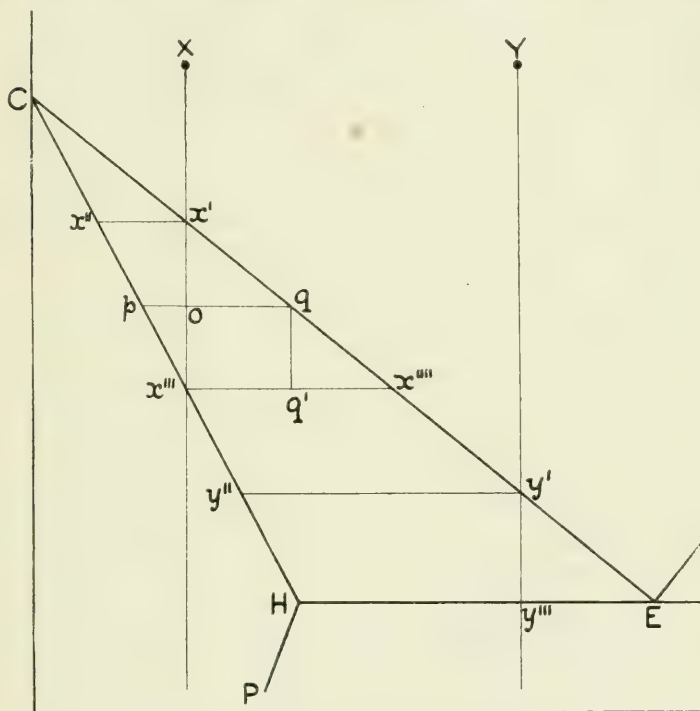


FIG. 2.—Part of Equilibrium Diagram, illustrating manner of solidification of two alloys, X and Y .

commences to solidify, and x''' is the temperature of complete solidification; or, if the solid alloy be heated, x''' is the temperature at which melting commences, and x' that of complete liquefaction. If attention is confined, for convenience, to the process of solidification of the melted alloy, the composition of the first tiny crystals is given by x'' , the intersection with the

* Roozeboom, *Zeitschrift physikalische Chemie*, 1899, vol. xxx. pp. 385, 413.

solidus of the horizontal line through x' . At any subsequent stage of solidification the compositions of the solid and liquid portions of the mass are represented by the intersections with the solidus and liquidus, respectively, of a horizontal line drawn at the temperature of the mixture in accordance with the vertical scale of the diagram. Thus, at the temperature of the line pq , the alloy X is a mixture of crystals of composition p with liquid of composition q . The total composition of the alloy is represented on the line pq by the point o , vertically below X , so that, by elementary geometry, the proportion of p -crystals is the fraction oq/pq , and the proportion of q -liquid is po/pq of the whole alloy. From x' to x''' the proportion of liquid steadily decreases and that of the crystals increases. At x''' the liquid vanishes, the composition of the last droplets being given by x'''' , the intersection with the liquidus of the horizontal through x''' .

In an alloy represented by a point like Y , lying between H and E , the earlier part of the process of solidification is like that of X , but the completion is otherwise. When the temperature has just fallen to that of the line HE the composition of the crystals is given by H and that of the liquid by E . The liquid E solidifies at constant temperature to form the eutectic, while the composition of the primary crystals remains unaltered, so that when the temperature commences to fall below HE the just solid alloy consists of primary crystals and eutectic in the proportion of $y'''E$ to Hy''' ; or $y'''E/HE$ of the whole consists of primary crystals and Hy'''/HE is formed of eutectic.

Returning to the alloy X , the process by which the solid portion changes from a few crystals of composition x'' to a homogeneous mass of composition x''' is of a duplex character. If just above the temperature pq all the crystals were removed from the liquid, a slight fall of temperature would bring about the generation of tiny crystals of composition p . But when the previously formed crystals are not removed and the conditions are those of equilibrium, the whole of the solid portion of the mixture attains the composition p at this temperature. There is a mutual action of diffusion between the solid and liquid portions, whereby the crystals formed at a higher temperature are enabled to assume, at the temperature pq ,

the only composition which is consistent with chemical equilibrium between solid and liquid at this temperature. If the process of solidification be supposed to take place in a series of small steps, at each step the crystals already formed change their composition, by diffusion, to that consistent with the new conditions of equilibrium, and there is also a small growth of entirely new material of the correct equilibrium composition.

In the above it has been supposed that the conditions of cooling are such that the alloy is enabled to be in a state of perfect physico-chemical equilibrium at the end of each small interval of temperature, but this is not so in practice. With ordinary rates of cooling, at any temperature within the interval of solidification, the composition of the liquid and of the most recently formed crystals probably approximate closely to those conditional with equilibrium, but such is not the case with the whole mass of solid. The process of diffusion, by which an alteration is effected in the composition of the primary crystals as the temperature falls, is a very slow one. It is much hindered also by the fact that the new growth is usually deposited around an already existing crystal, and forms an envelope which is for the moment in equilibrium with the liquid, and therefore more or less effectually screens the core. Thus, when solidification is completed, each crystal grain varies in composition from its centre to its external surface, giving a common and easily recognized type of structure. Further, any lack of equilibrium during solidification of an alloy having a composition to the left of H , such as X , causes the temperature of complete solidification to be lowered, but this does not fall below HE if surfusion be prevented; in an alloy having a composition between H and K , like Y , the proportion of eutectic is greater when there is imperfect than when there is perfect equilibrium. These last two statements will be understood by a reference to Fig. 2. Suppose that the alloy X cools to pq under conditions of perfect equilibrium. Then at this temperature the fraction oq/pq of the whole mass is solid. Suppose the crystals to be removed and the liquid to be cooled to $x'''x''''$, again under conditions of perfect equilibrium. Then the new crop of crystals is $q'x''''x'''x''''$ of the portion not removed, and $x'''q'x'''x''''$ of liquid remains.

Thus the mass is not completely solid at the temperature x''' , but a fraction equal to $x'''q'x'''x'''' \cdot po/pq$ of the original amount is still liquid. The sluggishness of diffusion may be conveniently regarded as equivalent to the removal of the crystals from the liquid at various stages in the process of solidification, so that an effect similar to the above is the result. If the rate of cooling of the alloy be very rapid, diffusion is almost entirely prevented; this is equivalent to replacing the two large steps of Fig. 2 by a great number of small ones. The temperature of complete solidification of an alloy to the left of H is then lowered to the eutectic temperature, and the proportion of eutectic in an alloy having a composition between H and E is increased. It is a useful and an interesting problem to determine the proportion of eutectic present in an alloy under these conditions.

II. DETERMINATION OF THE PROPORTIONS OF SOLID AND LIQUID IN A RAPIDLY COOLED ALLOY.

In considering the subject from a mathematical standpoint certain assumptions are required for the purpose of removing complexities difficult to treat accurately. The first assumption is that the manner of cooling is such that diffusion within the solid parts of the alloy is entirely prevented except during small temperature intervals which may be varied at will, while diffusion within the liquid portion is always perfect; consequently, each tiny crystal has the equilibrium composition corresponding with the temperature at the end of the interval within which it was formed. In an actual alloy there would be some diffusion within the solid portions, and a defective diffusion within the liquid portion of the mass. The second assumption is that all liquid remaining when the eutectic temperature is reached solidifies at this temperature; in the absence of surfusion this would be actually the case. It is further assumed, for the present, that both liquidus and solidus curves, CE and CH , are straight lines; for an actual series of alloys they are somewhat curved, but any desired degree of accuracy may be secured by subdividing the lines into sections short enough to be regarded as straight.

Consider an alloy represented by the point X , Fig. 3. Let its period of solidification be divided into a number of stages, as in the previous paragraph, the crystals being removed at

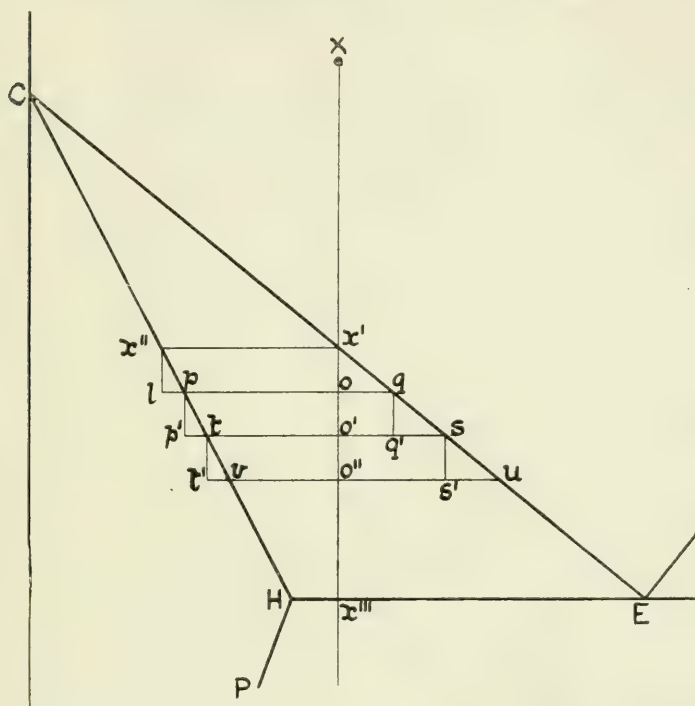


FIG. 3.—Part of Equilibrium Diagram in which the period of solidification of the alloy X is divided into a number of stages.

the end of each stage. At the end of the first stage the two parts of the mixture are in the proportions—

$$\left. \begin{array}{l} \text{Solid} = \frac{oq}{pq} \\ \text{Liquid} = \frac{po}{pq} \end{array} \right\} \text{ of the whole mass.}$$

At the end of the second stage the proportions are—

$$\left. \begin{array}{l} \text{Solid} = \frac{q's}{t_s} \\ \text{Liquid} = \frac{tq'}{t_s} \end{array} \right\} \begin{array}{l} \text{of the mass remaining after the removal} \\ \text{of the first crop of crystals.} \end{array}$$

That is, at the end of the second stage,

$$\left. \begin{aligned} \text{Solid} &= \frac{pq}{pq} + \frac{q's}{ts} \cdot \frac{p'o}{pq} \\ \text{Liquid} &= \frac{tq'}{ts} \cdot \frac{p''}{pq} \end{aligned} \right\} \text{ of the original mass.}$$

And so on for subsequent stages.

If the various steps extend over equal temperature intervals,

$$oq = q's = s'u, \text{ \&c. = say } m,$$

$$lp = p't = t'v, \text{ \&c. = say } n.$$

Put

$$x''s' = a.$$

Then

$$\left. \begin{aligned} pq &= a + m - n & ts &= a + 2m - 2n & ru &= a + 3m - 3n \\ p'o &= a - n & to' &= a - 2n & v'o'' &= a - 3n \\ & & tq' &= a + m - 2n & rs' &= a + 2m - 3n \end{aligned} \right\} \text{ \&c.}$$

And the proportions of solid and liquid may be written—

At end of first stage,

$$\left. \begin{aligned} \text{Solid} &= \frac{m}{a + m - n} \\ \text{Liquid} &= \frac{a - n}{a + m - n} \end{aligned} \right\} \text{ of original mass.}$$

At end of second stage,

$$\left. \begin{aligned} \text{Solid} &= \frac{m}{a + m - n} + \frac{m}{a + 2m - 2n} \cdot \frac{a - n}{a + m - n} \\ \text{Liquid} &= \frac{a + m - 2n}{a + 2m - 2n} \cdot \frac{a - n}{a + m - n} \end{aligned} \right\} \text{ of original mass.}$$

At end of third stage,

$$\left. \begin{aligned} \text{Solid} &= \frac{m}{a + m - n} + \frac{m}{a + 2m - 2n} \cdot \frac{a - n}{a + m - n} \\ &\quad + \frac{m}{a + 3m - 3n} \cdot \frac{a + m - 2n}{a + 2m - 2n} \cdot \frac{a - n}{a + m - n} \\ \text{Liquid} &= \frac{a + 2m - 3n}{a + 3m - 3n} \cdot \frac{a + m - 2n}{a + 2m - 2n} \cdot \frac{a - n}{a + m - n} \end{aligned} \right\} \text{ of original mass ;}$$

and so on.

At end of r -th stage,

$$\left. \begin{aligned} \text{Solid} &= \frac{m}{a + m - n} + \frac{m}{a + 2m - 2n} \cdot \frac{a - n}{a + m - n} + \dots \\ &\quad \dots + \frac{m}{a + rm - rn} \cdot \frac{a + (r-2)m - (r-1)n}{a + (r-1)m - (r-1)n} \cdot \dots \cdot \frac{a - n}{a + m - n} \end{aligned} \right\} (1)$$

$$\left. \begin{aligned} \text{Liquid} &= \frac{a + (r-1)m - rn}{a + rm - rn} \cdot \frac{a + (r-2)m - (r-1)n}{a + (r-1)m - (r-1)n} \cdot \dots \cdot \frac{a - n}{a + m - n} \end{aligned} \right\} (2)$$

of original mass.

It is simpler to determine the proportion of the liquid than of the solid portion of a mixture. The expression (2) gives the proportional amount of liquid remaining in an alloy at the end of a period of rapid cooling; if solidification has been completed, (2) gives the amount of liquid present at the eutectic temperature—that is, the amount of eutectic present in the just solid alloy. The degree of approximation to an accurate mathematical result for the case of an indefinitely great rapidity of cooling depends upon the number of steps taken—that is, upon the value of r —and for a reasonably accurate result this value must be considerable. A variation in the value of r is an artificial manner of representing a variation in the rate of cooling, though it is not possible to specify the actual rate of cooling which corresponds with a particular value of r .

When r is increased indefinitely, the expression (2) becomes an interesting example of a continued product of numbers, each less than unity, the value of which is finite. That the value is not zero follows from the fact that an increase in the value of r is only obtained by subdividing the steps, and each subdivision increases the value of the product. Thus, referring to Fig. 3, if the interval between $x'x'$ and ts be considered a single step—that is, if equilibrium conditions prevail throughout this period—the amount of liquid at the end of the step is

$$\frac{to'}{ts} = \frac{a-2n}{a+2m-2n} \text{ of that present at } x'.$$

If the period be divided into two equal steps by the line pq , the first crop of crystals being effectually removed at this temperature, the amount of liquid at the end of the second step is

$$\frac{tq'}{ts} \cdot \frac{po}{pq} = \frac{a+m-2n}{a+2m-2n} \cdot \frac{a-n}{a+m-n} \text{ of that present at } x'.$$

Now

$$\frac{a-2n}{a+2m-2n} = \frac{a-2n}{a+2m-2n} \cdot \frac{a+m-n}{a+m-n} = \frac{a^2+am-3an-2mn+2n^2}{(a+2m-2n)(a+m-n)}.$$

And

$$\frac{a+m-2n}{a+2m-2n} \cdot \frac{a-n}{a+m-n} = \frac{a^2+am-3an-mn+2n^2}{(a+2m-2n)(a+m-n)}.$$

So that the subdivision of the one step into two has increased the proportional quantity of liquid by

$$\frac{mn}{(a+2m-2n)(a+m-n)} \text{ of that present at } x'. \quad \dots (3)$$

Similarly, any other increase in the number of steps of the process causes a further increase in the amount of liquid left at the end. The quantity (3) is the amount of liquid necessary to convert the crystals of composition p , removed at the end of the first step, to the equilibrium composition t at the end of the second step. For, in order that the product shall have the composition t , the proportion of s -liquid which must diffuse into the p -crystals is

$$\frac{s\text{-liquid}}{p\text{-crystals}} = \frac{p't}{ts} = \frac{n}{a+2m-2n}.$$

And since the actual amount of p -crystals is

$$\frac{oq}{po} = \frac{m}{a+m-n} \text{ of the whole alloy,}$$

the liquid necessary for the reaction is

$$\frac{m}{a+m-n} \cdot \frac{n}{a+2m-2n} \text{ of the whole alloy.}$$

At the end of any subsequent stage the increased proportion of liquid over that conditional with equilibrium is less than the amount necessary to bring the whole of the crystals to the equilibrium composition corresponding with this temperature, since some of the increased liquid has crystallized at intermediate stages.

If the process of solidification were accomplished in one step—in other words, if conditions of perfect equilibrium prevailed during the whole period of crystallization of the solid solution—the proportional amount of liquid left in the mixture X (Fig. 3) at the eutectic temperature would be

$$\frac{Hx'''}{HE} = \frac{a-rn}{a+rm-rn} \quad \dots \quad (4)$$

Any subdivision of the process results in a greater proportion of liquid equal to

$$\frac{a-rn+Q}{a+rm-rn},$$

where Q is a quantity which depends upon the actual alloy, and upon the number of steps into which the period of solidification is supposed to be divided—that is, upon the extent to which diffusion is operative in the solid parts of the alloy. The expression (2) may be written in the above form; the details of the transformation are straightforward and uninteresting, and the result is that at the end of the r -th step,

$$\begin{aligned} \text{Liquid} = & \frac{1}{a+r(m-n)} \left[a-rn + \frac{{}^rC_2 mn}{\{a+(r-1)(m-n)\}} \right. \\ & + \frac{{}^rC_3 mn(m-2n)}{\{a+(r-1)(m-n)\}\{a+(r-2)(m-n)\}} + \dots \\ & + \frac{{}^rC_{s-1} mn(m-2n)(2m-3n) \dots \{(s-3)m-(s-2)n\}}{\{a+(r-1)(m-n)\} \dots \{a+[r-(s-2)](m-n)\}} + \dots \\ & \left. + \frac{mn(m-2n)(2m-3n) \dots \{(r-2)m-(r-1)n\}}{\{a+(r-1)(m-n)\} \dots \{a+m-n\}} \right] \dots \quad (5) \end{aligned}$$

where ${}^rC_2 = \frac{r(r-1)}{2 \cdot 1}$, ${}^rC_3 = \frac{r(r-1)(r-2)}{3 \cdot 2 \cdot 1}$, &c.

The expression (5) is usually convergent from the third term within the bracket, but the summation of the series is difficult; in certain cases the first few terms give a sensibly accurate result, but the form of the expression is inconvenient. The advantage in treating the subject in the above manner lies partly in its simplicity and clearness, and partly in the fact that the expression (2) is the most suitable to apply when the curvature of liquidus and solidus is to be taken into consideration, provided that the values of m and n proper to each point of the curves are inserted in the corresponding terms of the product. In order to obtain a more convenient expression for purposes of calculation, when liquidus and solidus are assumed to be straight, a somewhat different method of attack is required.

In Fig. 4, let the angle ACE be θ , and let ACH be ϕ . Let the difference of temperature between the freezing point C of the pure metal A and the freezing point x' of an alloy X be y_0 ; and let the difference of temperature between the freezing point C and some other temperature q of the partially solidified mixture be y . Let the temperature interval for a small

If solidification is completed above the eutectic temperature, the melting point of the alloy is obtained by equating the expression (6) to zero, which gives—

$$y = y_0 \cdot \frac{\tan \theta}{\tan \phi}$$

as the difference between the freezing point of the pure metal and the melting point of the alloy. If the proportion of eutectic is required in an eutectiferous alloy, it is obtained by inserting in (6) the value of y appropriate to the eutectic temperature.

For excessively rapid cooling the proportion of liquid left in the alloy X may be obtained by substitution in the expression (2), page 128.

Proportion of liquid (rapid cooling)

$$= \frac{y_0(\tan \theta - \tan \phi) - \delta y \tan \phi}{(y_0 + \delta y)(\tan \theta - \tan \phi)} \cdot \frac{y_0(\tan \theta - \tan \phi) + \delta y(\tan \theta - 2 \tan \phi)}{(y_0 + 2\delta y)(\tan \theta - \tan \phi)} \cdot \dots \cdot \frac{y_0(\tan \theta - \tan \phi) + \delta y(r-1) \tan \theta - r \tan \phi}{(y_0 + r\delta y)(\tan \theta - \tan \phi)}.$$

Writing $y_1 = y_0 + \delta y$, $y_2 = y_0 + 2\delta y$, &c., the expression becomes—

$$\frac{y_0(\tan \theta - \tan \phi) - \delta y \tan \phi}{y_1(\tan \theta - \tan \phi)} \cdot \frac{y_1(\tan \theta - \tan \phi) - \delta y \tan \phi}{y_2(\tan \theta - \tan \phi)} \cdot \dots \cdot \frac{y_{r-1}(\tan \theta - \tan \phi) - \delta y \tan \phi}{y_r(\tan \theta - \tan \phi)}.$$

Rearranging, and writing c for $\frac{\tan \phi}{\tan \theta - \tan \phi}$, the expression becomes—

$$\frac{y_0(\tan \theta - \tan \phi) - \delta y \tan \phi}{y_r(\tan \theta - \tan \phi)} \cdot \left[\left\{ 1 - \frac{c \cdot \delta y}{y_1} \right\} \left\{ 1 - \frac{c \cdot \delta y}{y_2} \right\} \dots \dots \left\{ 1 - \frac{c \cdot \delta y}{y_{r-1}} \right\} \right].$$

Proceeding to the limit, multiplying and collecting the terms within the square bracket, gives—

$$\frac{y_0}{y_r} \left[1 - c\delta y \Sigma \frac{1}{y} + (c\delta y)^2 \Sigma \text{(products of } \frac{1}{y} \text{ in pairs)} - (c\delta y)^3 \Sigma \text{(products of } \frac{1}{y} \text{ in threes)} + \&c. \right]$$

Now the series within the square bracket is convergent for any value of y with which it is necessary to deal as regards the present subject, and so long as no great number of terms are necessary, the expression may be rewritten, with only a slight deviation from perfect accuracy, as—

$$\begin{aligned} & \text{Proportion of liquid (rapid cooling)} \\ &= \frac{y_0}{y_r} \left[1 - c \int_{y_0}^{y_r} \frac{dy}{y} + c^2 \int_{y_0}^{y_r} \frac{dy}{y} \left(\int_{y_0}^{y_r} \frac{dy}{y} \right) - \&c. \right] \\ &= \frac{y_0}{y_r} \left[1 - c \log_e \frac{y_r}{y_0} + \frac{1}{2} \left(c \log_e \frac{y_r}{y_0} \right)^2 - \frac{1}{3} \left(c \log_e \frac{y_r}{y_0} \right)^3 + \&c. \right] \\ &= \frac{y_0}{y} \cdot e^{-c \log_e \frac{y_r}{y_0}} = e^{-(c+1) \log_e \frac{y_r}{y_0}} = e^{-\frac{\tan \theta}{\tan \theta - \tan \phi} \cdot \log_e \frac{y_r}{y_0}} \dots \dots (7) \end{aligned}$$

This result, though mathematically only an approximation, is of a much higher order of accuracy than it is possible or desirable to obtain in a numerical calculation of the proportion of liquid.

III. EXAMPLE—THE LEAD-TIN ALLOYS.

To illustrate the kind of results obtained by the above method the lead-rich alloys of the lead-tin series have been chosen. Most of the equilibrium conditions for this series have been determined recently with great accuracy by Rosenhain and Tucker.* The liquidus for the lead-rich alloys is slightly curved, and is shown as a fine line in Fig. 5; the eutectic point is at 62.93 per cent. of tin and 183° C. The corresponding solidus has not been determined exactly; the limiting concentration of the lead-rich solution is close to 16 per cent. of tin.

For the present purpose both solidus and liquidus have been assumed straight, and the intersections of these lines with the eutectic line have been taken at 16 and 63 per cent. of tin respectively; the assumed liquidus and solidus are shown as thick lines in Fig. 5. The curvature of the liquidus is taken into account in a subsequent calculation. The temperature interval between the freezing point of lead (328° C.) and that

* Rosenhain and Tucker, *Philosophical Transactions*, 1909, vol. ccix. A., p. 89.

of the eutectic (183° C.) has been divided into ten equal parts; the corresponding points of division on the liquidus represent nine lead-rich alloys, numbered I, II, III, &c., for which the calculations have been made. In order to show the effect of different rates of cooling, the interval between the freezing

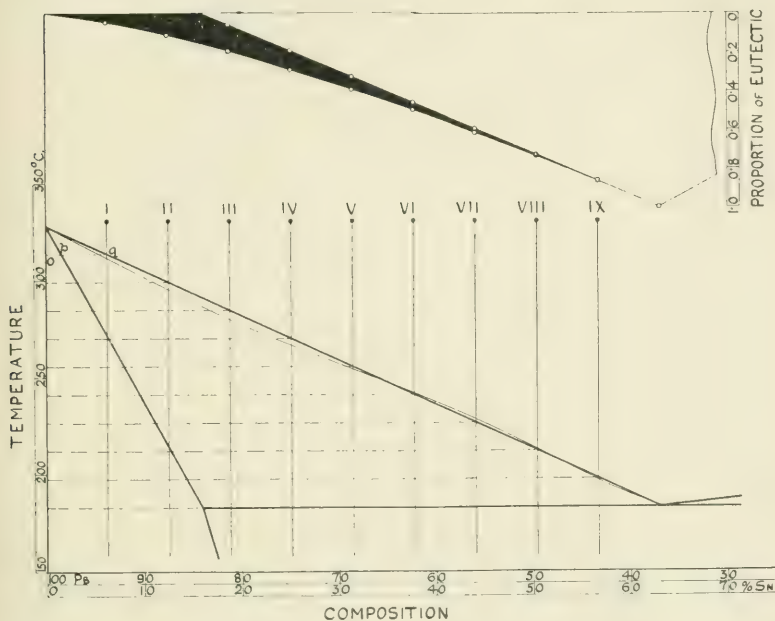


FIG. 5.—Part of Equilibrium Diagram for Lead-tin Alloys. The fine curved liquidus is drawn from the experimental results of Rosenhain and Tucker; the thick straight liquidus is the one assumed for most of the calculations. The points with Roman numerals attached represent the compositions of the alloys chosen for calculation. In the upper part of the diagram an ordinate of the straight sloping line represents the proportion of eutectic present in a just solid alloy when in a condition of equilibrium, and an ordinate of the curved line represents the proportion of eutectic in an alloy cooled with extreme rapidity.

point of lead and that of the eutectic has been divided into 10, 20, 50, 100, and 200 steps respectively, and the corresponding proportions of liquid left at 183° have been calculated from the expression (2), p. 128. These are given in Table I., together with the proportions of liquid left in the various alloys when the rate of cooling is indefinitely rapid, as calculated

from the expression (7), and also the proportions of liquid obtained under equilibrium conditions.

As an example of the method of calculation the case of 100 steps may be taken. For each alloy the horizontal distance between solidus and liquidus at the freezing point, designated a in the preceding section, is an even multiple of the difference between the small horizontal steps m and n ; for brevity the letter k is written hereafter for the difference ($m - n$). Then,

$$m = 63/100 = 0.63,$$

$$n = 16/100 = 0.16,$$

$$k = m - n = 0.47.$$

For alloy I. (Fig. 5),

$$op = 10n = 1.6 \text{ per cent. of tin,}$$

$$oq = 10m = 6.3 \text{ per cent. of tin,}$$

$$pq = a = 10(m - n) = 10k = 4.7.$$

And the number of steps between the freezing point q and the eutectic temperature is $r = 90$.

For alloy II.,

$$a = 20k, \text{ and } r = 80 \text{ steps.}$$

For alloy III.,

$$a = 30k, \text{ and } r = 70 \text{ steps ;}$$

and so on.

It is most convenient to begin with alloy IX., for which $a = 90k$, and $r = 10$ steps. Substituting in equation (2) of the preceding section, and writing k for ($m - n$),

For alloy IX,

$$\begin{aligned} \text{Liquid} &= \frac{a + 9k - n}{a + 10k} \cdot \frac{a + 8k - n}{a + 9k} \cdot \dots \cdot \frac{a + k - n}{a + 2k} \cdot \frac{a - n}{a + k} \\ &= \frac{99k - n}{100k} \cdot \frac{98k - n}{99k} \cdot \dots \cdot \frac{91k - n}{92k} \cdot \frac{90k - n}{91k} \\ &= \frac{46.37}{47.00} \cdot \frac{45.90}{46.53} \cdot \dots \cdot \frac{42.61}{43.24} \cdot \frac{42.14}{42.77} \\ &= 0.86807. \end{aligned}$$

Under equilibrium conditions,

$$\begin{aligned} \text{Liquid} &= \frac{a - 10n}{a + 10k} = \frac{90k - 10n}{100k} = \frac{40.7}{47.0} \\ &= 0.86596. \end{aligned}$$

For alloy VIII.,

$a=80k$, and $r=20$ steps.

$$\begin{aligned}\text{Liquid} &= \frac{a+19k-n}{a+20k} \cdot \frac{a+18k-n}{a+19k} \cdot \dots \cdot \frac{a+k-n}{a+2k} \cdot \frac{a-n}{a+k} \\ &= \frac{99k-n}{100k} \cdot \dots \cdot \frac{90k-n}{91k} \cdot \frac{89k-n}{90k} \cdot \dots \cdot \frac{80k-n}{81k} \\ &= \frac{46.37}{47.00} \cdot \dots \cdot \frac{42.14}{42.77} \cdot \frac{41.67}{42.30} \cdot \dots \cdot \frac{37.44}{38.07} \\ &= 0.74105.\end{aligned}$$

The product of the first ten terms for alloy VIII. is equal to the result already found for alloy IX., so that the arithmetic is not so formidable as it appears. Similarly, with alloy VII., it is only necessary to obtain the product of ten fractions and to multiply this by the proportion of liquid found for alloy VIII., and so on.

When the rate of cooling is indefinitely rapid the expression (7), p. 134, is used in the following manner:

$$\text{Liquid} = \epsilon^{-\frac{\tan \theta}{\tan \theta - \tan \phi} \cdot \log_{\epsilon} \frac{y_r}{y_0}}$$

$$\log_{\epsilon} \text{Liquid} = -\frac{\tan \theta}{\tan \theta - \tan \phi} \cdot \log_{\epsilon} \frac{y_r}{y_0}$$

Or, more conveniently,

$$\log_{10} \text{Liquid} = -\frac{\tan \phi}{\tan \theta - \tan \phi} \cdot \log_{10} \frac{y_r}{y_0}.$$

For alloy III., having its freezing point at 284.5°C. ,

$$y_0 = 328 - 284.5 = 43.5,$$

$$y_r = 328 - 183 = 145.$$

$$\frac{y_r}{y_0} = \frac{10}{3}; \log_{10} \frac{y_r}{y_0} = 0.5228787,$$

$$\frac{\tan \theta}{\tan \theta - \tan \phi} = \frac{63}{63 - 16} = 1.3404255,$$

$$\frac{\tan \theta}{\tan \theta - \tan \phi} \cdot \log_{10} \frac{y_r}{y_0} = 0.7008798,$$

$$\log_{10} \text{Liquid} = -0.7008798 = \bar{1}.2991202,$$

$$\text{Liquid} = .1991224.$$

It is quite clear from Table I. that for ordinary purposes a sufficient degree of approximation to the amount of liquid left when cooling is indefinitely rapid is obtained from expression (2) when the interval between the freezing points of pure lead and the lead-tin eutectic is divided into 100 steps.

TABLE I.—*Liquid Remaining in Various Lead-tin Alloys at the Eutectic Temperature after Different Rates of Cooling. (Liquidus and Solidus Assumed Straight.)*

No.	Freezing Point, Degrees C.	Tin per Cent.	Proportion of Liquid left at 183 Degrees C.						
			∞ Steps.	200 Steps.	100 Steps.	50 Steps.	20 Steps.	10 Steps.	Equilibrium.
I.	313.5	6.3	0.04566	0.04519	0.04470	0.04370	0.04047	0.03420	0.00000
II.	299.0	12.6	0.11563	0.11510	0.11456	0.11344	0.11002	0.10370	0.00000
III.	284.5	18.9	0.19912	0.19859	0.19804	0.19691	0.19356	0.18746	0.06170
IV.	270.0	25.2	0.29281	0.29230	0.29179	0.29068	0.28759	0.28194	0.19574
V.	255.5	31.5	0.39490	0.39443	0.39398	0.39299	0.39023	0.38521	0.32979
VI.	241.0	37.8	0.50443	0.50385	0.50346	0.50256	0.50026	0.49602	0.46383
VII.	226.5	44.1	0.61996	0.61966	0.61935	0.61859	0.61683	0.61350	0.59787
VIII.	212.0	50.4	0.74148	0.74127	0.74105	0.74045	0.73930	0.73698	0.73191
IX.	197.5	56.7	0.86829	0.86818	0.86807	0.86785	0.86716	0.86596	0.86596

The values given in the fourth and last columns of Table I. are plotted in the form of a diagram in the upper part of Fig. 5, where the proportion of liquid remaining in each alloy at 183° C. is set vertically downwards along the line representing the composition of the alloy. The straight line from 16 to 63 per cent. of tin shows the variation in the proportion of liquid with change in the composition of the alloy when the conditions are those of equilibrium; the curved line from pure lead to 63 per cent. of tin indicates the larger proportion of liquid found when cooling is rapid. For clearness the space between the two lines is shown black. Since the liquid remaining in any alloy at 183° solidifies at this temperature in the form of the lead-tin eutectic, the diagram also represents the proportion of eutectic present in the various solid alloys under the stated conditions.

This diagram is of peculiar interest in connection with Tammann's method of determining the ends of an eutectic line.* The method consists in noting, for a number of alloys having compositions between that of the eutectic and that of the saturated solid solution, the time during which the temperature remains stationary at the eutectic freezing point; if the conditions of cooling are identical for all the alloys these

* Tammann, *Zeitschrift anorganische Chemie*, 1903, vol. xxxvii. p. 303; 1905, vol. xlv. p. 24; 1905, vol. xlvii. p. 289.

times are proportional to the amounts of eutectic solidifying, and when time is plotted against composition the point at which the proportion of eutectic is zero—that is, the limit of saturation of the solid solution—is found by extrapolation. The difficulties in accurately applying this method are considerable, but the chief objection to the results obtained by most of the investigators who have employed it is in the small quantities of material they have used, and the common accompaniment of rather rapid cooling. As a consequence nearly all the published data give curved lines like the curved one of Fig. 5. The latter gives the upper limit to the proportion of eutectic when the cooling is very rapid, while the straight line gives the lower limit corresponding with equilibrium. The experimental curves mentioned fall between these two limits; they give too low a saturation point for the solid solution, that is, too long an eutectic line. The mere fact that they are curved is conclusive evidence either that the rate of cooling of the alloys has been too rapid to give results consistent with equilibrium, or that there have been other sources of error, since for equilibrium the proportion of eutectic varies simply with the composition of the alloy, so that all curves of this nature should be straight lines.

The equation to the curve which represents the proportion of eutectic in a series of rapidly cooled alloys is obtained from (7) by inserting the value of y_r —say y_E —corresponding with the eutectic temperature. The expression may also be written somewhat more conveniently thus :

Let E be the proportion of eutectic in a rapidly cooled alloy.

Let X be the percentage of the metal B in the alloy.

Let X_s be the percentage of the metal B in the A-rich solid solution H.

Let X_E be the percentage of the metal B in the eutectic.

Then (Fig. 4),

$$X = y_0 \tan \theta,$$

$$X_s = y_E \tan \phi,$$

$$X_E = y_E \tan \theta.$$

And

$$E = \epsilon^{-\frac{X_E}{X_E - X_s} \cdot \log_e \frac{X_E}{X}} \dots \dots \dots (7a)$$

is the equation to the curve, where E is the ordinate corresponding with the abscissa X , and the other terms are constants proper to the series of alloys.

For the lead-rich alloys of the lead-tin series,

$$E = \epsilon^{-\frac{63}{47} \log \epsilon} \frac{63}{X}$$

gives the proportion of eutectic in a rapidly cooled alloy X .

It is clear from Fig. 5 that a much closer approximation to the true saturation point is found by extrapolation through points obtained from alloys rich in eutectic than from those containing only a small proportion of eutectic, whenever the rate of cooling falls short of the extreme slowness necessary to ensure equilibrium. The same fact is brought out still more clearly in Fig. 8, which shows the various apparent positions of the saturation point as determined from the proportion of eutectic in the rapidly cooled alloys, in the manner detailed on p. 147. The real saturation point is at H , 16 per cent. of tin; the points h_1 , h_2 , h_3 , &c., are obtained for alloys I., II., III., &c., respectively, when rapidly cooled, and correspond with the percentages of tin given in the bottom line of Table III. They actually represent the average composition of the non-uniform primary crystals of each alloy. The horizontal scale of Fig. 8 is more open than that of Fig. 5, in order that the various points shall be clearly separated.

It is interesting to determine what proportion of an alloy has crystallized at any instant during its period of solidification. This is easily calculated, by the methods given already, both for a rapidly cooled and for a very slowly cooled alloy. Table IIA. gives the proportion of solid matter in each of the nine chosen alloys at nine equidistant temperatures between the freezing point of lead and that of the lead-tin eutectic, and also at the eutectic temperature, when the alloys are very rapidly cooled; Table IIB. gives corresponding figures for the same alloys when in perfect equilibrium, the liquidus and solidus being assumed straight.

TABLE IIA.—*Proportion of Primary Crystals in quickly cooled Lead-tin Alloys at various Temperatures. (Liquidus and Solidus assumed straight.)*

No. of Alloy . . .	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
Tin per Cent. . . .	6·3	12·6	18·9	25·2	31·5	37·8	44·1	50·4	56·7
Temp., Degrees C. {									
313·5	0·000	...	...	...	...	...	...	...	...
299·0	0·605	0·000	...	...	...	...	...	...	...
284·5	0·771	0·419	0·000	...	...	...	...	...	...
270·0	0·844	0·605	0·320	0·000	...	...	...	...	...
255·5	0·884	0·707	0·496	0·258	0·000	...	...	...	...
241·0	0·909	0·771	0·605	0·419	0·217	0·000	...	...	...
226·5	0·926	0·814	0·679	0·528	0·363	0·187	0·000	...	...
212·0	0·938	0·844	0·732	0·605	0·467	0·320	0·164	0·000	...
197·5	0·947	0·867	0·771	0·663	0·545	0·419	0·286	0·146	0·000
183·0	0·954	0·884	0·801	0·707	0·605	0·496	0·380	0·258	0·132

TABLE IIB.—*Proportion of Primary Crystals in Lead-tin Alloys under conditions of Equilibrium at various Temperatures. (Liquidus and Solidus assumed straight.)*

No. of Alloy . . .	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
Tin per Cent. . . .	6·3	12·6	18·9	25·2	31·5	37·8	44·1	50·4	56·7
Temp., Degrees C. {									
313·5	0·000	...	...	...	...	...	...	...	...
299·0	0·670	0·000	...	...	...	...	...	...	...
284·5	0·894	0·447	0·000	...	...	...	...	...	...
270·0	1·000	0·670	0·335	0·000	...	...	...	...	...
255·5	1·000	0·804	0·536	0·268	0·000	...	...	...	...
241·0	1·000	0·894	0·670	0·447	0·223	0·000	...	...	...
226·5	1·000	0·957	0·766	0·574	0·383	0·191	0·000	...	...
212·0	1·000	1·000	0·838	0·670	0·503	0·335	0·168	0·000	...
197·5	1·000	1·000	0·894	0·745	0·596	0·447	0·298	0·149	0·000
183·0	1·000	1·000	0·938	0·804	0·670	0·536	0·402	0·268	0·134

The above values are represented diagrammatically in Fig. 6. From the freezing point of each alloy is drawn to the right a short horizontal line, the length of which represents unit quantity of the mixture; verticals are drawn from the ends of this line to the eutectic line. From the left-hand vertical line, at each of the temperatures given in the first column of Table IIA., the corresponding proportion of primary crystals of the quickly cooled alloy is set out horizontally, and the points so obtained are joined by a curve. The proportion of

liquid present in the mixture at any temperature is obviously given by the horizontal distance between this curve and the right-hand vertical boundary of the rectangle. The portion of each rectangle which represents solid matter is labelled *S*, and that representing liquid is marked *L*. In the same way as for the rapidly cooled alloys, a curve for each slowly cooled alloy is plotted from the data of Table IIB.; each of the latter curves lies to the right of the corresponding one of the former series, in accordance with the fact that there is more solid and less liquid matter in the slowly cooled alloys. The

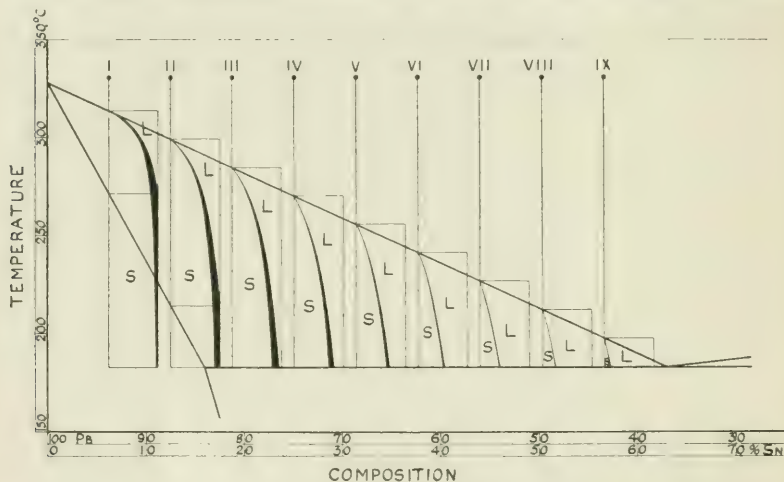


FIG. 6.—Part of Equilibrium Diagram for Lead-tin Alloys, showing the relative proportions of liquid and solid in each of the nine chosen alloys, at all temperatures during the period of crystallization, for very slow and for very rapid cooling.

space between each pair of curves, shown black for clearness, exhibits the effect of rapid cooling in reducing the proportion of primary crystals. For rapid cooling the spaces marked *L* include the narrow dark areas; for slow cooling the dark areas are to be reckoned as parts of the spaces marked *S*. The alloys I. and II., when slowly cooled, become completely solid at temperatures above 183° , and at these temperatures the difference between quickly cooled and slowly cooled alloy is greatest. In alloys near the eutectic composition, like VIII. and IX., the effect of rapid cooling is very small.

If the curves of Fig. 6 are differentiated, either by a

graphical or by a mathematical method, other curves are obtained which represent the varying rate of solidification during the period of freezing of each alloy. Such curves are drawn in Fig. 7 for alloys I., III., and VII., the original curves, which differ only in scale from those of Fig. 6, being shown in full lines and the derived rate curves in dotted lines. The initial rate of crystallization is the same for both slow and rapid cooling. From the expression (6), page 132, it follows that,

Proportion of solid at any temperature (slow cooling),

$$= 1 - \text{Proportion of liquid}$$

$$= 1 - \frac{y_0 \tan \theta - y \tan \phi}{y(\tan \theta - \tan \phi)} = \frac{\tan \theta}{\tan \theta - \tan \phi} \cdot \frac{y - y_0}{y}.$$

Differentiating this with respect to y ,

$$\text{Rate of solidification (slow cooling)} = \frac{\tan \theta}{\tan \theta - \tan \phi} \cdot \frac{y_0}{y^2} \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad (8)$$

At the freezing point, $y = y_0$, so that for both slow and rapid cooling,

$$\begin{aligned} \text{Rate of solidification at freezing point} &= \frac{\tan \theta}{\tan \theta - \tan \phi} \cdot \frac{1}{y_0} \\ &= \frac{63}{47} \cdot \frac{1}{y_0}, \text{ for lead-tin alloys.} \end{aligned}$$

The above rate of solidification is in respect of fall of temperature, but it is convenient also to express the rate with regard to the composition of the crystals; this does not alter the shape of the curves if the solidus is straight, since the composition of the crystals formed at any temperature varies directly as the distance of that temperature from the freezing point of the pure metal, that is, with y . Hence,

$$\begin{aligned} \text{Rate of solidification with respect to composition (slow cooling),} \\ &= \frac{\tan \theta}{\tan \theta - \tan \phi} \cdot \frac{y_0}{y} \cdot \frac{1}{\text{composition of crystals}}. \end{aligned}$$

And the rate at freezing point

$$= \frac{63}{47} \cdot \frac{1}{\text{initial composition of crystals}}, \text{ for lead-tin alloys.}$$

Thus the rate of solidification at the freezing point of alloy I., with respect to composition $= \frac{63}{47} \cdot \frac{1}{1.6} = 0.8378$.

Or, more simply, using the notation of p. 128,

$$\begin{aligned} \text{Rate of solidification} &= \frac{\text{Proportion of solid deposited}}{\text{Change of composition of solid}} \\ &= \frac{\frac{m}{a+r(m-n)} \cdot (\text{pre-existing liquid}) + \frac{n}{a+r(m-n)} \cdot (\text{pre-existing solid})}{n} \\ &= \frac{\frac{m}{a+r(m-n)} \cdot \frac{a-rn}{a+r(m-n)} + \frac{n}{a+r(m-n)} \cdot \frac{rm}{a+r(m-n)}}{n} \\ &= \frac{m}{n} \cdot \frac{a}{\{a+r(m-n)\}^2} \cdot \cdot \cdot \cdot \cdot \cdot (9) \end{aligned}$$

At the freezing point $r = 0$, and the rate is

$$\frac{m}{n} \cdot \frac{1}{a} = \frac{\tan \theta}{\tan \phi} \cdot \frac{1}{a}.$$

That is, for alloy I. the rate is $\frac{63}{16} \cdot \frac{1}{4.7}$, the same as above.

For alloys containing no eutectic, the rate of solidification at the melting point, when the last drop of liquid solidifies, is, since, at this point, $a = rn$,

$$\begin{aligned} &\frac{m}{n} \cdot \frac{rn}{\{rn+r(m-n)\}^2} = \frac{1}{rm}, \\ &= \frac{1}{\text{Horizontal distance between solidus and liquidus at melting point}}. \end{aligned}$$

Thus, the slowly cooled alloy I. becomes completely solid when

$$y \tan \phi = y_0 \tan \theta = 6.3.$$

The corresponding value of rm is

$$\begin{aligned} \tan \theta (y - y_0) &= y_0 \tan \theta \left(\frac{\tan \theta}{\tan \phi} - 1 \right) \\ &= 6.3 \cdot \frac{.47}{16} \\ &= 18.51, \end{aligned}$$

a value which may be measured, of course, upon the equilibrium diagram. The final rate of solidification

$$= \frac{1}{18.51} = 0.0540.$$

The rate of solidification at the melting point of an alloy

which contains eutectic, and any intermediate rates, may be obtained by substituting suitable values in (9), but in Fig. 7 the differentiation has been performed graphically, except for the initial and final points of each curve.

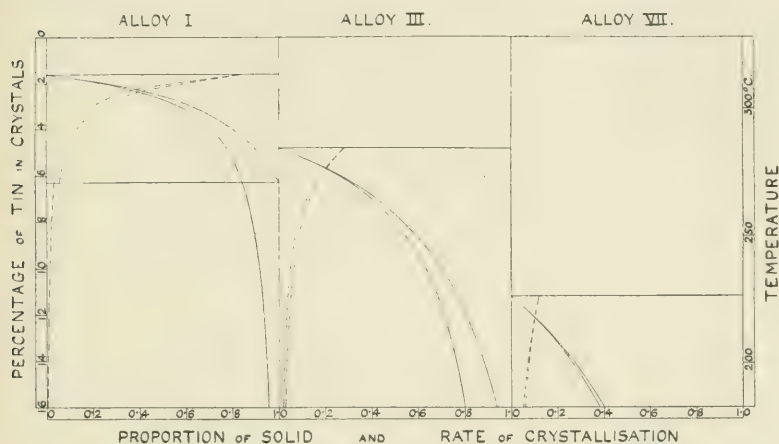


FIG. 7.—Diagrams similar to those of Fig. 6, but to a larger scale, for alloys I., III., and VII. The dotted curves are obtained by differentiating the full-line curves, and represent the varying rate of crystallization.

For rapidly cooled alloys the rate of solidification with respect to fall of temperature is obtained from the expression (7), page 134, thus—

Proportion of solid at any temperature (rapid cooling)

$$= 1 - \text{liquid} = 1 - \epsilon^{-(c+1) \log_e \frac{y}{y_0}}$$

where c is written for $\frac{\tan \phi}{\tan \theta - \tan \phi}$.

Differentiating this with respect to y gives,

Rate of solidification (rapid cooling)

$$\begin{aligned} &= (c+1) \cdot \epsilon^{-(c+1) \log_e \frac{y}{y_0}} \cdot \frac{1}{y} \\ &= \frac{\tan \theta}{\tan \theta - \tan \phi} \cdot \epsilon^{-\frac{\tan \theta}{\tan \theta - \tan \phi} \cdot \log_e \frac{y}{y_0}} \cdot \frac{1}{y} \quad \dots (10) \end{aligned}$$

Or, with regard to composition, as explained above,

Rate of solidification

$$= \frac{\tan \theta}{\tan \theta - \tan \phi} \cdot \epsilon^{-(c+1) \log_e \frac{y}{y_0}} \cdot \frac{1}{\text{Composition of crystals just being formed}}.$$

But the proportion of liquid remaining at this temperature is

$$\epsilon^{-(c+1) \log_e \frac{y}{y_0}}.$$

Therefore the rate of solidification

$$= \frac{\tan \theta}{\tan \theta - \tan \phi} \cdot \frac{\text{Proportion of liquid}}{\text{Composition of separating crystals}} \quad \dots (11)$$

At the freezing point $y = y_0$, so that (10) reduces to

$$\frac{\tan \theta}{\tan \theta - \tan \phi} \cdot \frac{1}{y_0}$$

which is identical with the result for slow cooling.

The expression (11) may be obtained very simply, thus—

$$\text{Rate of solidification} = \frac{\text{Proportion of solid deposited}}{\text{Change of composition of solid}}$$

$$= \frac{\frac{m}{a+r(m-n)} \cdot \text{liquid}}{n}.$$

Now

$$\frac{m}{n} = \frac{\tan \theta}{\tan \phi};$$

and

$$\frac{\text{Composition of separating crystals}}{a+r(m-n)} = \frac{\tan \phi}{\tan \theta - \tan \phi}, \text{ by simple geometry.}$$

Therefore the rate of solidification

$$= \frac{\tan \theta}{\tan \theta - \tan \phi} \cdot \frac{\text{Proportion of liquid}}{\text{Composition of separating crystals}}$$

as before.

The final rate of solidification of the primary crystals of the rapidly cooled alloy I. is

$$\frac{63}{47} \cdot \frac{0.4566}{16} = 0.0038$$

where the proportion of liquid remaining at 183° has been taken from Table I. Intermediate values may be obtained

by suitable substitution or by graphical means, as in Fig. 7. From the rate curves of Fig. 7 it is possible to deduce the theoretical forms of cooling curve which correspond with a very slow and with a very rapid rate of cooling respectively.

From the data given in Table IIA. the average composition of the primary crystals of each rapidly cooled alloy at a stated temperature may be calculated if, as already assumed, the composition of the liquid is always that indicated by the liquidus. The point which represents the average composition of the crystals is a point on the apparent solidus for that particular alloy when rapidly cooled. The average composition of the primary crystals, by simple arithmetic, is equal to

$$\frac{(\text{Composition of alloy}) - (\text{proportion of liquid} \cdot \text{composition of liquid})}{\text{Proportion of solid}}$$

Thus for alloy I., at a temperature of 270° , the proportion of solid (see Table IIA.) is 0.844, and the proportion of liquid is 0.156. The composition of the alloy is 6.3 per cent. of tin, and that of the liquid part of it is 25.2 per cent. of tin. Hence,

$$\begin{aligned} &\text{Average composition of primary crystals of alloy I. at } 270^{\circ} \\ &= \frac{6.3 - (0.156 \cdot 25.2)}{0.844} = 2.81 \text{ per cent. of tin.} \end{aligned}$$

For very slow cooling the composition (from Fig. 5) is 6.4 per cent. of tin, so that the effect of rapid cooling is to cause a very considerable shift of the apparent solidus to the left. Values calculated in this manner for the alloys I. to IX. at various temperatures are given in Table III., and the corresponding solidus curves are shown as fine lines in Fig. 8. Certain published solidus curves show the same kind of hollow curvature as these, but it must not be concluded on that account that they are incorrect.

In order to show the effect of varying the rate of cooling, the values given in Table IV. have been obtained in the same manner as those above, but with a greater degree of accuracy; they represent the average composition of the primary crystals of alloy I. at the eutectic temperature, corresponding with the various proportions of liquid left in this alloy as listed in Table I. Under conditions of equilibrium the alloy I., of

course, becomes completely solid at a temperature far above that of the eutectic point. The figures of Table IV. are not

TABLE III.—*Average Composition of Primary Crystals of Rapidly Cooled Lead-tin Alloys at Various Temperatures.*

No. of Alloy	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	Equilibrium Composition.
Tin per Cent.	6.3	12.6	18.9	25.2	31.5	37.8	44.1	50.4	56.7	
Temp., Degrees C.										
313.5	1.6	...	...	...	...	...	...	...	...	1.6
299.0	2.19	3.2	...	...	...	...	...	...	...	3.2
284.5	2.56	3.87	4.8	...	...	...	...	...	...	4.8
270.0	2.81	4.37	5.50	6.4	...	...	...	...	...	6.4
255.5	2.99	4.77	6.09	7.09	8.0	...	...	...	...	8.0
241.0	3.15	5.12	6.56	7.73	8.80	9.6	...	...	...	9.6
226.5	3.28	5.40	6.98	8.29	9.39	10.43	11.2	...	...	11.2
212.0	3.38	5.61	7.36	8.74	9.93	11.03	12.01	12.8	...	12.8
197.5	3.48	5.84	7.68	9.19	10.46	11.60	12.62	13.56	14.4	14.4
183.0	3.57	5.99	7.94	9.53	10.93	12.22	13.27	14.15	15.30	16.0

valuable in themselves, since the real rates of cooling cannot be specified; but they show the approach towards equilibrium

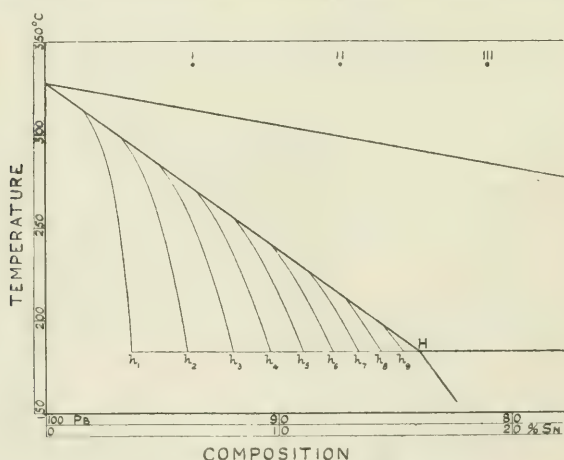


FIG. 8.—Part of Equilibrium Diagram for Lead-tin Alloys, showing the apparent forms of solidus and the apparent positions of the saturation point obtained from rapidly cooled alloys.

conditions, on account of the greater opportunity for diffusion, as the rate of cooling is decreased.

TABLE IV.—*Apparent Saturation Point for Alloy I. at Different Rates of Cooling.*

Rate of Cooling Represented by Number of Steps in Freezing Process.	Average Composition of Primary Crystals at 183° C. Tin per Cent.
∞	3.587
200	3.616
100	3.647
50	3.709
20	3.908
10	4.292

If the curvature of the liquidus and solidus is to be taken into account, it is not possible to make use of so simple an expression as (7), but the expression (2) is quite suitable when the correct values of m and n , which now vary from point to point, are inserted. For the lead-tin alloys the form of the liquidus, as determined by Rosenhain and Tucker, is shown as a fine line in Fig. 5, but since the form of the solidus is not yet known it has been assumed straight as before. The proportional quantities of liquid have been calculated only for the comparatively simple case in which the temperature interval between the freezing points of pure lead and of the eutectic is divided into ten equal steps.

The slope of the liquidus, as represented by the value of m , first increases from 5.4 to 7.4, then decreases to 5.6, and then rises again to 6.7; with the assumed straight liquidus, m had the constant value 6.3. The slope of the solidus is given, as formerly, by $n = 1.6$. The details of the calculations are of the same kind as those on page 136. In Table V. the values obtained for the true curved liquidus are compared with the corresponding results (10 steps, Table I.) found when the liquidus was assumed straight. As the temperatures in both cases are the same, the corresponding equilibrium proportions of liquid differ in the two cases, and these are tabulated also for the purpose of comparison. Now the proportion of eutectic present in any alloy under conditions of equilibrium at the eutectic temperature depends only upon the composition of the alloy, the composition of the eutectic, and the composition of the saturated primary crystals; it is quite independent of any curvature of the liquidus and solidus. One might expect, not unreasonably, therefore, that a similar result should be

found to hold good for more quickly cooled alloys. That this is very nearly so may be seen from Fig. 9, in which the results of Table V. are shown graphically. The open circles represent the values obtained when the liquidus is assumed straight, and the black dots when the curvature is taken into account; the termination of the curve at 1.6 per cent. of tin, instead of at 0 per cent., is in accordance with the fact that only ten steps have been taken. The straight line ending at



FIG. 9.—Diagram showing the calculated proportion of eutectic in lead-tin alloys cooled at a moderate speed: \circ , when liquidus is assumed straight; \bullet , when true curved form of liquidus is taken. The fine straight line shows the equilibrium proportion of eutectic.

1.6 per cent. of tin represents the result of cooling under conditions of equilibrium. The amount of eutectic in a quickly cooled alloy can be obtained very closely, therefore, by assuming liquidus and solidus straight and making use of the comparatively simple expression (7), much of the labour involved by taking a large number of steps, with varying values of m and n , and using (2), being thereby avoided. Similarly, the proportion of liquid present in a quickly cooled alloy, at a temperature between its freezing and melting points, may be obtained from (7) if θ and ϕ are the inclinations of straight lines drawn from the freezing point of the pure metal to the

points representing the actual compositions of liquid and solid at the temperature considered.

TABLE V.—*Comparison of Proportional Amount of Liquid found from Assumed Straight Liquidus with that found from True Curved Liquidus.*

No. of Alloy.	Freezing Point, Degrees C.	Liquidus Assumed Straight.			True Curved Liquidus.		
		Tin per Cent.	Liquid at 183° C.		Tin per Cent.	Liquid at 183° C.	
			10 Steps.	Equilibrium.		10 Steps.	Equilibrium.
I.	313.5	6.3	0.03420	0.00000	5.4	0.02249	0.00000
II.	299.0	12.6	0.10370	0.00000	11.0	0.07974	0.00000
III.	284.5	18.9	0.18746	0.06170	16.8	0.15434	0.01702
IV.	270.0	25.2	0.28194	0.19574	23.4	0.25229	0.15745
V.	255.5	31.5	0.38521	0.32979	30.8	0.37352	0.31489
VI.	241.0	37.8	0.49602	0.46383	38.1	0.50214	0.47021
VII.	226.5	44.1	0.61350	0.59787	44.8	0.62721	0.61277
VIII.	212.0	50.4	0.73698	0.73191	50.7	0.74285	0.73830
IX.	197.5	56.7	0.86596	0.86596	56.3	0.85745	0.85745

IV. REHEATING OF QUICKLY COOLED ALLOYS.

The results of the preceding paragraphs are of interest in connection with the method of determination of the solidus by reheating various solid alloys of a series to definite temperatures, and examining them microscopically for signs of incipient melting. It is possible in this manner to obtain a close approximation to the true melting point of an alloy, provided the mixture is in a condition of equilibrium at the moment when melting begins. If the alloy is one which should contain no eutectic, and if it has had insufficient annealing to bring it to a condition of equilibrium, the observed melting point will be lower than the true one. An alloy but slightly within the saturation limit may contain some eutectic, and its melting point will be the eutectic point; in an alloy somewhat less rich than this the external envelope of each primary crystal may have a composition only just less than that of saturation, and so on. For a series of alloys, which have all received a similar and insufficient annealing treatment, the apparent saturation limit of the primary crystals will be reduced, the solidus will be depressed, and will merge

gradually into the eutectic line instead of meeting the latter abruptly; its form will be somewhat like that of the dotted curve in Fig. 10. The conditions are probably too complex

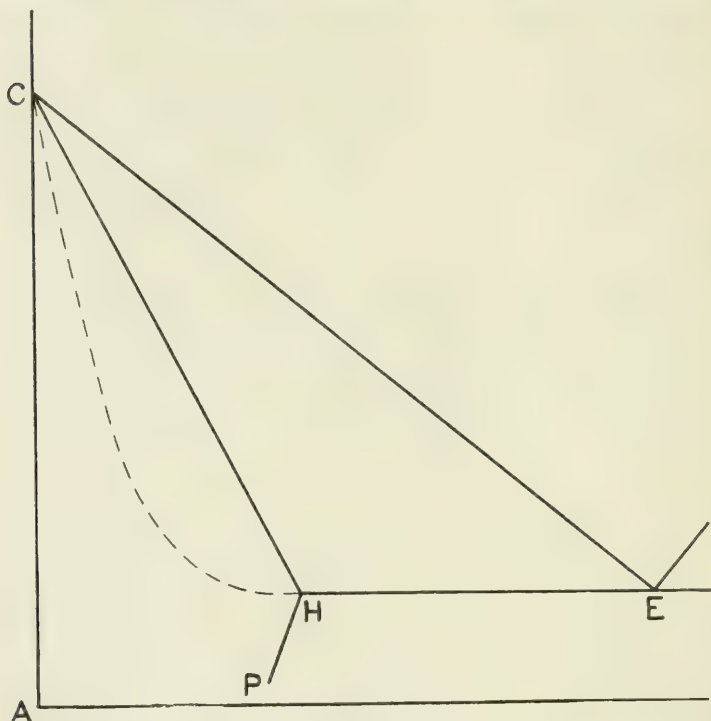


FIG. 10.—Sketch showing dotted the shape of solidus to be expected when determined by reheating alloys which are in a condition of imperfect equilibrium.

and uncertain for any useful calculation, but the possibility of error of the kind described requires considerable care for its complete avoidance. A curve of the form sketched in Fig. 10 should be certainly received with caution.

V. SUMMARY.

From an equilibrium diagram for a series of alloys of which the structural constituents are two solid solutions and an eutectic, it has been shown possible to determine the constitution of a rapidly cooled alloy of the series, if certain simple assumptions are made.

The method has been applied to the lead-rich alloys of the lead-tin series. The proportion of eutectic in a just solid alloy, the proportion of liquid and of solid in an alloy at a temperature between its freezing and melting points, and the rate of solidification of an alloy at a given temperature, when slowly and when rapidly cooled, have been calculated. The apparent form of solidus obtained from a rapidly cooled alloy has been shown, together with the variation in the apparent position of the saturation point which accompanies variation in the rate of cooling. The position of the apparent saturation point depends not only upon the rate of cooling, but still more upon the composition of the alloy. The proportion of eutectic present in a rapidly cooled alloy is sensibly independent of the curvature of liquidus or solidus, if this is not excessive.

The apparent form of solidus obtained from insufficiently annealed alloys has been indicated.

In conclusion, it should be hardly necessary to point out that the methods employed herein are not confined to alloys in which an eutectic is present, but are equally applicable to the numerous cases in which there is a transformation of a partly solid mixture, if this transformation proceeds during an interval of temperature when the conditions are those of equilibrium. The determination of the constitution of an alloy cooled with extreme rapidity should be of considerable practical interest, since the equilibrium diagram shows at sight the constitution of the alloy when cooled with extreme slowness, and the constitution of an alloy cooled at some intermediate rate, as in all practical operations, must lie between the two extreme limits. It is an advantage that there is no necessity to wait for the determination of the true form of liquidus, solidus, or solubility curves before making the necessary calculations, so long as the limiting points—eutectic, transformation, and saturation points—are known with fair accuracy. Although certain physical influences have been ignored in the foregoing discussion, it is believed that results calculated from accurate data by the methods given are not much wide of the truth.

DISCUSSION.

Professor T. TURNER, M.Sc. (Honorary Treasurer and Vice-President), said the paper was an extremely useful contribution, as the President had stated, but it was one more suitable for studying at home than for discussion at a meeting. The author's work in connection with various types of alloys was well known, and one could not help desiring to compliment him on the application of the simple geometrical method in the first part of the paper. He took first a typical case, and then worked out by geometrical methods the composition of the result of liquid and of crystallized solid. He was reminded in looking at that method of treatment of the subject of Newton's method of doing calculations by simple geometry, calculations which otherwise were only to be done by means of the calculus. The author was not able to escape the calculus altogether later on, and he there gave some calculations which those who still remembered the calculus would be able to verify quietly at home. He was sure the paper would be one of useful reference, and the thanks of the Institute were due to the author for contributing it to the Proceedings.

Professor A. K. HUNTINGTON, Assoc.R.S.M. (President), thought that a theoretical paper such as the one under discussion was of great use if only it would fit the practice, or the practice would fit the theory. There were, however, little differences between them. For instance, with regard to the question of cores, they persisted much longer than the author gave them credit for very often. The author spoke of the first separation and the solutions redistributing themselves, but he was not quite sure that they did so as rapidly as he imagined. He had occasion a year or two back to deal with a 500 lb. billet of cupro-nickel with some 12 per cent. of nickel in it. The billet was very slowly cooled down from the bottom upwards, and at the end of the operation there were some ounces of material squeezed out, which he examined, and he found it had from 7 or 8 per cent. of nickel in it instead of the 12 per cent. it ought to have had. It evidently never redistributed itself, and there was a considerable difference in the composition of the billet at different points under the conditions it was made. There was no doubt, from a practical point of view, that, however delightful theories were, they were sometimes very difficult to fit in with practice.

COMMUNICATIONS.

Dr. CECIL H. DESCH (Glasgow) wrote that Mr. Gulliver's interesting communication involved a great deal of careful mathematical work, and would be useful in showing clearly the direction and magnitude of some of the principal errors in the method of thermal analysis. It must, however, be understood that such elaborate mathematical treatment

would be very rarely applicable to concrete cases. It could only be applied to observations which had been made with a high degree of accuracy, and investigators who were capable of making such observations were now careful to cool their alloys under such conditions that equilibrium was attained as nearly as possible, and in such cases a mathematical correction would be unnecessary. On the other hand, the method could not be employed for the correction of rough preliminary surveys of metallic systems. In the author's own words: "There is no necessity to wait for the determination of the true form of liquidus, solidus, or solubility curves before making the necessary calculations, so long as the limiting points—eutectic, transformation, and saturation points—are known with fair accuracy." The accurate determination of these points was, however, precisely what was lacking in the ordinary rough determinations of the liquidus and solidus. The use of small quantities and of insufficiently slow cooling led to erroneous values for the eutectic composition, eutectic temperature, and limits of saturation. If these were determined with sufficient accuracy, it was probable that the whole series of observations would be suitable for direct application in the construction of a diagram, without mathematical treatment.

One of the author's conclusions on p. 140 was of great interest and importance for the proper interpretation of Tammann's "eutectic time" curves, namely, that "a much closer approximation to the true saturation point is found by extrapolation through points obtained from alloys rich in eutectic than from those containing only a small proportion of eutectic, whenever the state of cooling falls short of the extreme slowness necessary to ensure equilibrium." If this principle were applied to the very numerous diagrams issued from the Göttingen laboratory, it would be found that the eutectic horizontals would be shortened considerably in many cases, thus giving a greater range of composition to the solid solutions than had been originally assumed. Such a conclusion appeared to be in accordance with other evidence, particularly that from electrical conductivity.

Dr. ROSENHAIN, F.R.S. (Member of Council), wrote that he had read Mr. Gulliver's paper with very great interest. He felt that it was an important contribution to the study of the constitution of alloys in general, and that it was particularly valuable because it furnished a means of deducing from a properly established equilibrium diagram the approximate metastable constitution of rapidly cooled alloys, and *vice versa*. It indicated how observations made on rapidly cooled alloys tended to mislead the investigator in regard to the true constitution of the system. He was particularly pleased with Mr. Gulliver's development of this subject, because in a very general way he had already drawn attention to the matter in a paper to which Mr. Gulliver frequently referred, viz., An investigation of "The Alloys of Lead and Tin," published in the *Philosophical Transactions of the Royal Society* in 1909. In fact, that paper contained a diagram illustrating the manner in which rapid cooling may prolong the eutectic line far beyond its proper termination. Mr.

Gulliver had no doubt seen that diagram, and he (Dr. Rosenhain) hoped that perhaps it had served to stimulate Mr. Gulliver's quantitative examination of the subject.

Dr. Rosenhain had no criticism to offer on Mr. Gulliver's mathematical treatment of the subject, and he hoped that future investigators of alloys would not fail to consider the points raised in the present paper. There was, however, one point on which he wished to utter a word of caution. This referred to the diagram Fig. 10 of the present paper. The danger of finding an incorrect solidus curve by quenching experiments on alloys insufficiently annealed was no doubt very real; on the other hand, a number of investigations on solidus curves by this method had already been made, and had yielded forms of solidus very similar to that shown by the dotted line in Mr. Gulliver's Fig. 10. Now in one case, viz., the aluminium-zinc solidus investigated by Dr. Rosenhain and Mr. Archbutt, very great care indeed had been taken to secure that the alloys before reheating should have reached a condition closely approximating to complete equilibrium, and microscopic examination of the specimens themselves when quenched just below the solidus, showed their structure to be homogeneous. There should, therefore, be no question in that case of incomplete equilibrium sufficient to displace the observed solidus from its true position. Yet that system had yielded a solidus which approximated fairly closely to the kind of curve shown in Fig. 10. Therefore, although the danger of finding an incorrect solidus from alloys not in equilibrium had been rightly emphasized by Mr. Gulliver, he would warn investigators that they must not conclude that a solidus was necessarily incorrect because it approximated to the form of the dotted curve in Fig. 10.

Mr. GULLIVER, writing in reply to the discussion, thanked those gentlemen who had shown such kind appreciation of his paper, but he did not think that his work merited a comparison with that of Newton. He was quite in accord with Professor Huntington as to the persistence of cores, and could not find any remark in which he (the author) suggested that the redistribution of material in a non-uniform solid solution was a rapid process; he had, in fact, laid emphasis upon its slowness. Professor Huntington's cupro-nickel billet was a very interesting example to the author, since he had, only a few weeks ago, worked out at some length the constitution of rapidly cooled copper-nickel alloys. In an alloy containing 12 per cent. of nickel the first crystals to form would contain about 25 per cent. of nickel. At any temperature in the period of partial solidification the average composition of the crystals would lie between 12 and 25 per cent. of nickel, and the liquid portion would contain less than 12 per cent. of nickel, just as Professor Huntington found. In order to obtain an approximately uniform solid solution of the nickel in the copper a long period of annealing would be necessary.

The author thought that Dr. Desch had somewhat misunderstood the main object of his work, which was to obtain an accurate idea of the constitution of alloys cooled under industrial conditions; the present

communication was certainly very incomplete in that respect, but it formed a step in the right direction. He hoped to advance the subject by another step shortly. He thought the matter had been suggested to him originally by a remark in one of the admirable papers of Messrs. Heycock and Neville, before Dr. Rosenhain's paper on the lead-tin alloys was published. When drawing Fig 10 he had in mind not the aluminium-zinc, but the iron-carbon solidus; he was much indebted to Dr. Rosenhain for such positive information as to the care taken in the determination of the aluminium-zinc solidus, as this completely set at rest the doubts he had formerly entertained as to the accuracy of such a form.

PRACTICAL HEAT TREATMENT OF ADMIRALTY GUN-METAL.*

BY H. S. PRIMROSE (MESSRS. G. & J. WEIR LTD., CATHCART) AND
J. S. G. PRIMROSE (ROYAL TECHNICAL COLLEGE, GLASGOW).

IN his paper to the Institute on a former occasion,† one of the authors made the suggestion that if gun-metal were subjected to heat treatment, such as quenching and annealing at various temperatures, profound changes would be found to take place in the properties of the metal.

Since then this joint research has been undertaken with the object of finding a simple and reliable method of improving Admiralty gun-metal so as to obtain the highest possible tensile strength without reducing the percentage elongation, and at the same time imparting to it a greater soundness and homogeneity of structure. So far as the authors are aware no previous work has been published dealing with this subject as applied to the most commonly used industrial alloy known as Admiralty gun-metal, of which the specification is 88 per cent. of copper, 10 per cent. of tin, and not more than 2 per cent. of zinc, with a maximum variation of 1 per cent. of any of its component metals. This composition is readily obtained in practice which is under proper metallurgical control, but even when the analysis closely agrees with the specification it is sometimes difficult to produce castings which fulfil the requisite physical tests attaining a tensile strength of 14 tons per square inch, and an elongation of 7·5 per cent. on a 2-inch test-bar. Many practical founders and some experimenters have experienced considerable trouble in making sound castings with this alloy to stand a high water-pressure; and undoubtedly the internal structure of the metal has a great deal to do with this important property, as well as with the other characteristics.

Although blowholes are the commonest known source of

* Read at Annual General Meeting of the Institute of Metals, London, March 12, 1913.

† "Metallography as an Aid to the Brassfounder," by H. S. Primrose, *Journal of the Institute of Metals*, No. 2, 1910, vol. iv.

unsoundness in gun-metal, these may be entirely absent and still the castings are not completely satisfactory when submitted to the physical tests and hydraulic pressure, owing to the imperfect arrangement of the constituents. Even when the physical tests are complied with and the structure under the microscope is of the interlocking design with uniformly inter-mixed primary crystallites and interspacial eutectoid, the metal as cast may fail under water pressure owing to the water sweating through the microscopical pores formed between the two constituents. These constituents are of widely different chemical composition, and possess different coefficients of contraction.

When ordinary gun-metal is cast and slowly cooled, the first portions to solidify consist of primary crystallites of the α -constituent, which is copper containing all the zinc and only a small quantity of tin in solution in it. As the crystals continue growing and the temperature falls, an increasing amount of tin is held in solution by the solidifying α -constituent, and at the moment of solidification the interspaces are filled with the β -constituent, which is copper containing still more tin in solution. As this β -solution is only stable through a short range of temperature, on cooling it undergoes decomposition with the formation of the eutectoid containing the white δ -constituent (Cu_4Sn); and the dark-etching, littoral zones of secondary α -constituent. It is between these two latter constituents that the microscopic crevices occur, and they are so small that the fractured surface does not reveal their presence. It might appear possible to produce gun-metal castings in which the eutectoid areas were so small and uniformly distributed that they would not be in a connected meshwork throughout the mass. Chilling the metal in the mould has this effect by preventing the decomposition of the β -constituent, but in actual practice it is not possible to so control the rate of solidification and cooling that the eutectoid segregations are always prevented from arranging themselves in a harmful way.

METHOD OF PROCEDURE.

In carrying out the tests it was deemed advisable to adhere to the customary "inch-round" bars 10 inches long, which were

cast from gun-metal at a temperature just below 1100°C. , both into dry-sand moulds and chills, with the object of producing either slow or rapid solidification as desired. The rate of cooling was dependent upon the arrangement of the boxes, and was moderately slow for dry-sand castings, comparatively quick for chills alone, and very slow when the metal was cast in chills placed in close proximity to and in connection with a large body of metal cast at the same time. Two sets of duplicate bars were used in all cases, and these were prepared for testing and after-treatment, by turning the central portion down to a diameter of $\frac{5}{8}$ -inch, giving a cross-sectional area of 0.306 square inch over a suitable length for a 2-inch test-piece.

In the tensile testing machine employed, only the ultimate breaking strain was taken. The elongation was also determined. The average value of the results from the four bars have been tabulated, correct to the first decimal place. In none of the tests recorded did the tensile strength vary by more than 1 per cent. and the elongation by 5 per cent. between maximum and minimum.

In performing the experimental tests of heat-treatment the bars were heated gradually to the required temperature in a Heraeus electric resistance furnace, thus minimizing the oxidation of the metal; and no appreciable loss of zinc was noticed even at the higher temperatures. The bars were maintained for a definite time at the fixed temperature as determined accurately by a pyrometer, and then either quenched in water or cooled off in the furnace, which took about two hours to attain normal temperature. The test-bars were not subsequently dressed or burnished, as this was found to interfere with the physical condition of the bar; burnishing especially imparted a skin to the metal which materially raised the tensile strength. Sections were cut from each bar, and after having been polished on the transverse cut and etched in the usual way with ferric chloride, they were examined microscopically and typical structures were photographed.

The plan adopted in marking the specimens was as follows:—

First letter.—Series of the tests: E, F, G, H, K.

Second letter.—Method of casting: In dry-sand (D.), in chills (C.).

Third letter.—Heat treatment: annealed (A.); Normal as cast (N.), quenched (Q.).

First figure.—Temperature of heating: 500° C. (5), 600° C. (6), 650° C. (6½).

Second figure.—Time of annealing: 5 minutes (V.), 10 minutes (X.), (if not stated), 30 minutes (XXX.).

QUENCHING.

In view of the excellent results obtained by Guillet* on quenching pure bronzes of various composition, from temperatures between 600° C. and 700° C., it was thought that gun-metal would also show an increase in the strength and the elongation if similarly treated. This, however, was not found to be the case, as there was a considerable reduction in the values got on tensile testing, and evidently the presence of the small proportion of zinc exercises a profound influence on the character of the metal. Thus in Series "E," in which the test-bars were cast in dry-sand moulds at a moderate temperature of about 1060° C., ensuring both slow solidification and slow cooling, and then heated slowly (after turning to size) to temperatures ranging from 500° C. to 800° C. before quenching, the physical properties were very considerably poorer than that of the normal cast bars. This is shown in Table I., the values of which are given graphically in Fig. 1.

It is noteworthy that the elongation falls off consistently with the rise of quenching temperature, and also that it follows the drop in tensile strength almost proportionately. The lowest values are got with the quenching temperature of 700° C., when the tensile strength is only about one-third that of the normal bars, and the elongation about one-ninth. From this and subsequent tests it is evident that there must be some radical change in the constitution of the alloy in the vicinity of this temperature.

The microscope gives interesting evidence of the physical changes taking place in the metal as the temperature rises. In Fig. 7, Plate V., is seen the normal interlocking structure of a sound gun-metal casting, with the eutectoid uniformly distributed throughout the interspaces of the primary α -constituent, and surrounded by the littoral zones of secondary α .

* L. Guillet, "Quenching of Bronze," *Revue de Métallurgie*, February 1905.

The contraction cavities in the eutectoid areas are shown in the higher magnification photograph of the same metal in Fig. 8, Plate V., the holes being more marked in the larger portions of the eutectoid.

The heating to 500° not only increases the size of the

TABLE I.—*Influence of Quenching Temperature on Dry-sand Castings.*

Mark.	Quenched from Degrees C.	Tensile Strength. Tons per Sq. In.	Elongation per Cent.
E.D.N.	...	15.6	28.0
E.D.Q. 5	500	8.2	12.0
E.D.Q. 6	600	6.5	7.5
E.D.Q. 7	700	4.9	3.0
E.D.Q. 8	800	9.0	5.5

Series "E", Graph of Table I.

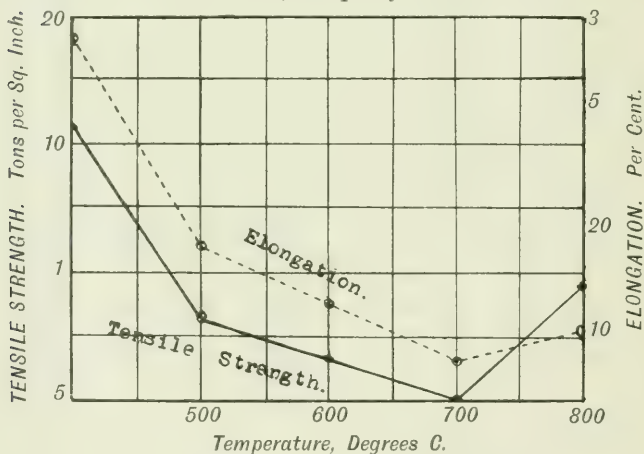


FIG. 1.—Influence of Quenching Temperature.

crystals in the metal, but has caused a slight change in the nature of the crystallites. There appears to be a small amount of secondary α -constituent assimilated by the primary crystallites, although there has been practically no change in the amount of separated eutectoid. This is shown in Fig. 9, Plate V.

At 600° a still larger crystal structure is produced, and a considerable amount of the eutectoid has been absorbed, form-

ing with the secondary α a large proportion of the β -constituent which has been retained in that state by the quenching. Fig. 10, Plate V.

Further heating to 700° completes the solution of the δ -constituent of the eutectoid, and the β assumes with the α a rectangular formation which is most remarkable, and occurs throughout all the crystals. These are now extremely large and show a tendency to disjunction at the outer edges of the specimen. This structure is shown in Fig. 11, Plate V.

Heating to 800° produces an almost homogeneous structure, as here only α crystallites exist together with portions of the metal which have undergone incipient fusion. The quenching retains these portions chiefly at the boundaries of the crystals, as shown in Fig. 12, Plate V. The small dark specks scattered through the ground-mass are minute segregations of lead formed during the reheating.

It is thus evident that reheating and quenching gun-metal castings does not effect any improvement, even if this were possible without damaging the shape of the casting. In practice it is not feasible to quench the metal immediately after it has solidified, although this may have been done with test-bars which were quenched direct, without having been first cooled to the ordinary temperature, and then reheated, as were the bars tested in this series.

ANNEALING.

The simple operation of annealing was next tried upon sets of test-bars which were cast and cooled in a variety of ways. The treatment consisted of a gradual heating up to various temperatures, at which they were maintained for various periods of time. The subsequent cooling in each case was moderately rapid until 400° was attained, after which it was comparatively slow.

Series "F."—In this series the bars were cast in dry-sand moulds with the same metal and from the same temperature as Series "E." This treatment produced a slow solidification of the metal, followed by a moderately slow cooling. This is the general type to which most gun-metal castings belong,

and it is of interest to note that the subsequent heat treatment effected a most remarkable improvement in the elongation of the specimens, without in any way diminishing the tensile strength of the material. Table II. gives the average results of the tensile testing, and these are represented in graph form in Fig. 2. Whilst the ultimate breaking strain of the metal is slightly increased as the annealing temperature rises to 700° , it falls off most remarkably at 800° . The

TABLE II.—*Influence of Annealing Temperature on Dry-sand Castings.*

Mark.	Annealed at Degrees C.	Time. Mins.	Tensile Strength. Tons per Sq. In.	Elongation per Cent.
F.D.N. . . . .	...	...	17.2	24.0
F.D.A. 5	500	30	15.1	26.5
F.D.A. 6	600	30	16.3	28.5
F.D.A. 7	700	30	18.0	37.5
F.D.A. 8	800	30	15.5	31.0

Series "F," Graph of Table II.

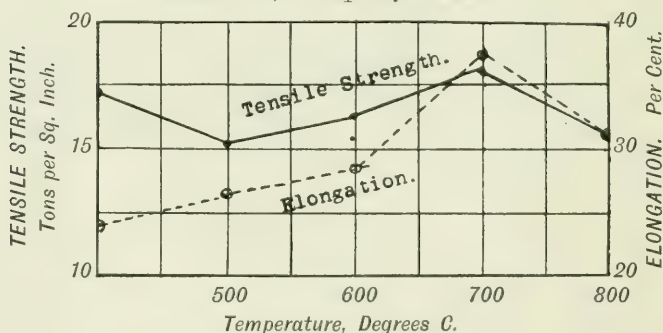


FIG. 2.—Influence of Annealing Temperature.

elongation is very considerably increased up to the temperature of 700° , after which it also falls away.

The microstructures of the series are shown in Plate VII., and differ in a most marked degree from those of Series "E." Figs. 19 and 20 show that the annealing temperatures of 500° and 600° respectively have been insufficient during the period of half an hour to completely remove the δ -constituent, and hence the eutectoid segregations still remain. At 700° ,

however, the reaction is practically complete, and Fig. 21, Plate VII., indicates that the cooling from this temperature after annealing is not attended by the separation of any appreciable quantity of δ -constituent. The small dark spots in the photomicrograph evidently represent the small proportion of lead which has been thrown out of solution at this temperature. The microstructure is very uniform, indicating a solid solution, and although the crystals are larger than in the normal bar, they are well orientated and in a strongly interlocking arrangement. The test-bars annealed at 800° , although cooled much more slowly than by quenching, show in the microstructure signs of incipient fusion having taken place at the small dark spots in the photograph. Fig. 22, Plate VII.

Series "G."—The bars of this set were cast in chills of solid metal, so that both the solidification and the cooling were rapid. In this case the annealing again produced a remarkable increase in the elongation, and this was attended by an almost equally striking increase in the tensile strength. The maximum results were again obtained by the annealing at 700° for thirty minutes, and lower results were got with bars heated to a point both above and below this temperature. Table III. and Fig. 3 give the average results obtained in the tests.

The microstructure of the metal is not much altered by annealing at 500° (see Fig. 23, Plate VII.), but a considerable change has taken place at 600° , all the δ -constituent having disappeared, and only α and β are left in the formation shown in Fig. 24, Plate VII. Almost pure α results from the annealing at 700° , and the low magnification photograph (Fig. 25, Plate VIII.) shows the crystalline structure of a solid solution. Fig. 26, Plate VIII., illustrates the similar structure got on annealing at 800° , which is, however, much larger in crystal formation, as shown by the low magnification.

Series "H."—In this, and the following series "K," the bars were cast in chills in close proximity to a large body of metal which was cast and cooled along with them, so that although their solidification was fairly rapid, the cooling afterwards was comparatively slow. The very great increase in both the

tensile strength and the elongation got by annealing for half an hour at 700° is again evident from Table IV. and Fig. 4, showing the average results obtained in testing. Intermediate points at 650° and 750° were taken, but in each case the results were inferior to those obtained at 700° .

TABLE III.—*Influence of Annealing Temperature on Chilled Castings.*

Mark.	Annealed at Degrees C.	Time. Mins.	Tensile Strength. Tons per Sq. In.	Elongation per Cent.
G.C.N. . . . .	...	...	15.0	4.0
G.C.A. 5	500	30	12.3	7.5
G.C.A. 6	600	30	19.6	25.0
G.C.A. 7	700	30	20.0	30.0
G.C.A. 8	800	30	17.2	22.5

Series "G," Graph of Table III.

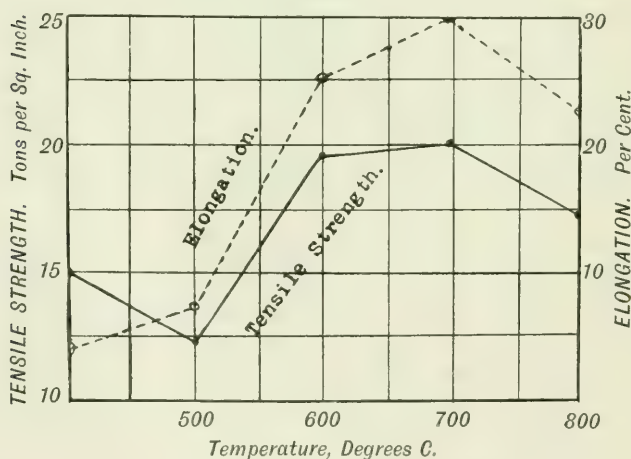


FIG. 3.—Influence of Annealing Temperature.

The changes in the microstructure are shown all together for the sake of comparison on Plate VI. The normal structure is similar to that of bar K.C.N., shown in Fig. 28, Plate VIII., and the annealing to 500° produces only a slight change in structure, which resembles that of bar G.C.A. 5, shown in Fig. 23, Plate VII. The change at 600° is more complete

and shown in Fig. 13, Plate VI. The annealing at 650° has only completed the change of the δ -constituent in the smaller crystals, so that the larger ones still show both β and δ (see Fig. 14, Plate VI.).

Figs. 15 and 16, Plate VI., are both micrographs of bar H.C.A. 7, showing at different magnifications the well-oriented

TABLE IV.—*Influence of Annealing Temperature on Chilled Castings.*

Mark.	Annealed at Degrees C.	Time. Mins.	Tensile Strength. Tons per Sq. In.	Elongation per Cent.
H.C.N. . . . .		...	18.6	20.0
H.C.A. 5	500	30	16.7	9.0
H.C.A. 6	600	30	15.0	7.0
H.C.A. 6½	650	30	19.5	27.0
H.C.A. 7	700	30	22.5	45.0
H.C.A. 7½	750	30	21.0	40.0
H.C.A. 8	800	30	18.6	34.0

Series "H," Graph of Table IV.

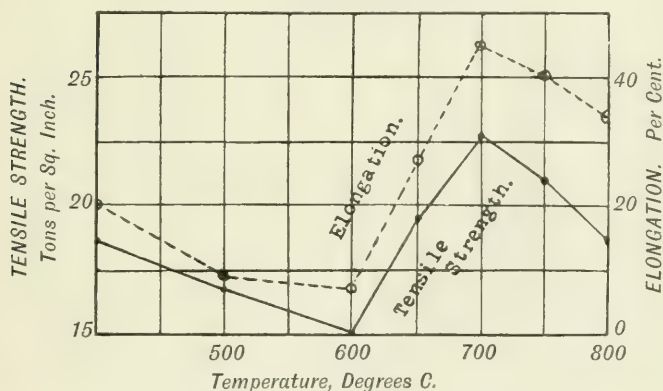


FIG. 4.—Influence of Annealing Temperature.

crystalline structure of the single α -constituent. Figs. 17 and 18, Plate VI., show the increase in the size of crystal growth by the further annealing to temperatures of 750° and 800° respectively. This is no doubt the reason for the falling off in both the tensile strength and the elongation.

Series "K."—The tests in this series were carried out with the object of determining the range of time during which the

heating should be continued in order to get the best results when annealing was done at the correct temperature of 700° . This is naturally dependent upon the thickness of the metal under treatment, but for the size of test-bars used ($\frac{5}{8}$ -inch diameter) this was shown to be somewhere about thirty

TABLE V.—*Influence of Time of Annealing on Chilled Castings.*

Mark.	Annealed at Degrees C.	Time. Mins.	Tensile Strength. Tons per Sq. In.	Elongation per Cent.
K.C.N. . . . .	...	...	16.5	15.0
K.C.A. V.	700	5	19.6	25.0
K.C.A. X.	700	10	20.4	35.0
K.C.A. XV.	700	15	21.2	37.0
K.C.A. XX.	700	20	21.4	40.0
K.C.A. XXV.	700	25	22.5	45.0
K.C.A. XXX.	700	30	23.1	48.5
K.C.A. LX.	700	60	21.2	39.5
K.C.A. CL.	700	150	20.5	37.0

Series "K," Graph of Table V.

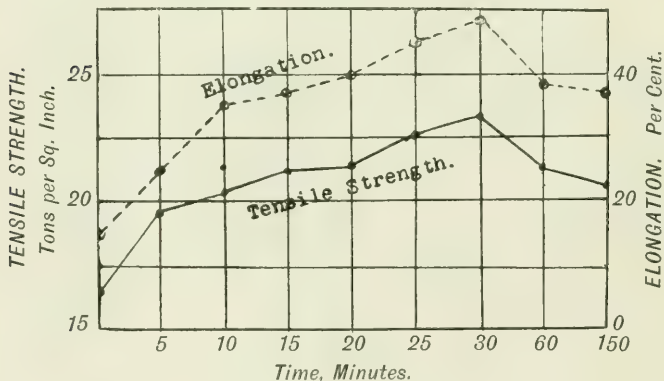


FIG. 5.—Influence of Time of Annealing at 700° C.

minutes, as seen from the results tabulated in Table V. and shown graphically in Fig. 5. The annealing for this period shows the maximum results both in tensile strength and elongation, but the increase is only slight after annealing has been carried on for twenty minutes. Very long continued annealing produces a slight diminution in the strength and elonga-

tion, but it is evident that if the right temperature of 700° be attained the time of annealing at this temperature may be varied within fairly wide limits without impairing the improvement effected in the structure and character of the metal.

The microstructure of the normal cast bar is shown in Figs. 27 and 28, Plate VIII., and the lower magnification micrograph taken with oblique illumination clearly indicates the oriented structure of this metal. Fig. 29, Plate VIII., represents the effect upon the structure of annealing for fifteen minutes at 700° , and the very slight alteration in this got by annealing for sixty minutes is shown in Fig. 30, Plate VIII.

THERMAL ANALYSIS.

The cooling of the metal from fusion is shown at (a) in Fig. 6 as an inverse rate curve, and represents the halt points

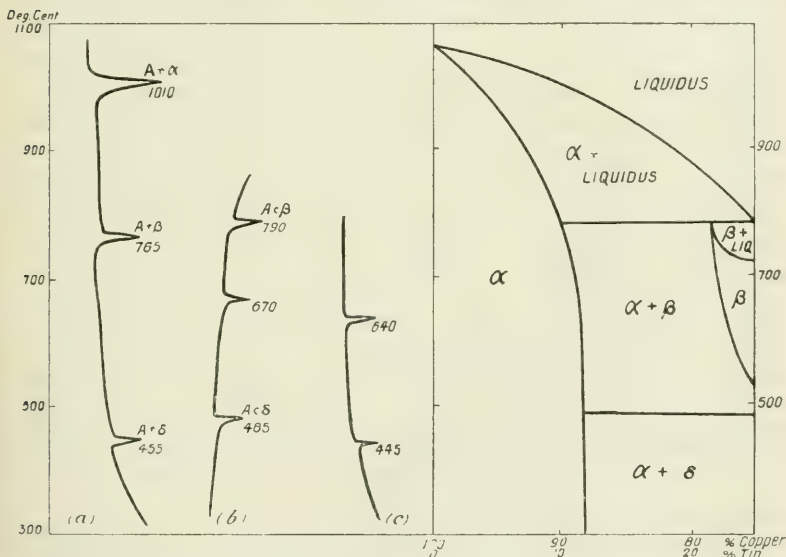


FIG. 6.—Inverse Rate Cooling and Heating Curves of Admiralty Gun-metal, with Freezing-point Diagram of Copper-tin Alloys for comparison.

as only very slightly different from those of the corresponding bronze in the freezing-point diagram of Shepherd and

Blough, a portion of which is reproduced for comparison. The heating curve shows that the reverse changes are not accompanied by very large absorptions of heat, as evinced by the curve (*b*), Fig. 6. The halt below 700° evidently marks the completion of the δ to β change. The inverse rate curve (*c*), Fig. 6, shows the cooling of the metal after annealing for sixty minutes at 800° , and indicates that although the β inversion still exists, there has been a considerable diminution of the δ change, as would be expected from the examination of the microstructure of the metal after annealing at this temperature.

PRACTICAL APPLICATIONS.

The importance of the annealing of gun-metal castings, which in service have to stand severe tests, must be abundantly evident from the foregoing results.

One great advantage it possesses lies in making the metal capable of complying with the most stringent specification as regards tensile strength and elongation, although it must be clearly pointed out that it cannot be regarded as "faking" the metal. Such metal as may be defective due to the presence of gas or blowholes, is not materially improved by this heat treatment: but when slight defects arise, due to the harmful segregation of the eutectoid structure, then this is completely removed by the proper annealing.

One of the most frequent tests now applied to important gun-metal castings is that of water pressure, and in many cases they fail most dismally under even moderate pressure. The metal is thus condemned as bad, whereas it is really quite good, and it is only a strange characteristic of the metal possessing the wrong arrangement of its constituents which makes it unsuitable for this purpose when cast and not further heat-treated as suggested in this paper.

Numerous castings of various designs made in the course of daily foundry practice have been rejected in this way, and these, on being annealed correctly, have in all cases been found to withstand the water pressure which previously they had failed to do. A large number of micrographs have been taken of specimens from such castings before and after anneal-

ing, but owing to the exigencies of space these are unable to be reproduced. In each case, after they had been treated, they showed similar structures to Fig. 15, Plate VI. and Fig. 25, Plate VIII.

Two particular instances are worth recording as showing the advantage of annealing material which, although apparently sound, has failed to comply with specified tests. They were both test-bars cut from large castings, and whilst the first gave a tensile strength of 14·4 tons, the elongation was only 5 per cent. when normal. On annealing this at 700° for thirty minutes the tensile strength was raised to 18 tons and the elongation was increased to 25 per cent. In the second case both the tensile strength and elongation were low in the normal bar, being 11 tons and 8 per cent. respectively. This metal was improved by annealing to give the remarkable results of 15 tons tensile strength and 26 per cent. elongation.

In putting this annealing process into practice in the workshop or foundry the chief item required is some type of muffle furnace of a size large enough to hold a number of the castings to be treated. For maintaining a uniform temperature during the annealing, as also for regulating the rate of heating and cooling, it is necessary to employ either gas or oil firing. The temperature must be controlled by a pyrometer installation, and the workman in charge of the operation should be under supervision to ensure that he does not exceed either the temperature or time limits found to be needed for each class of casting under treatment.

HARDNESS.

As it is sometimes of practical value to have an idea of the relative hardness of gun-metal under the various treatments accorded it, Table VI. has been prepared to show the changes

TABLE VI.—*Hardness of Heat-treated Gun-metal.*

Bars.		Normal.	500°.	600°.	700°.	800°.
Brinell's Hardness Numbers.	E.D.Q.	62	77	65	61	74
	F.D.A.	63	65	61	60	60
	G.C.A.	86	80	75	74	70

in the values got by the Brinell method of determining this property. It is noteworthy that the hardening effect of chilling the metal is even greater than that of quenching, and that annealing does not completely remove this difference.

Graph of Table VI.

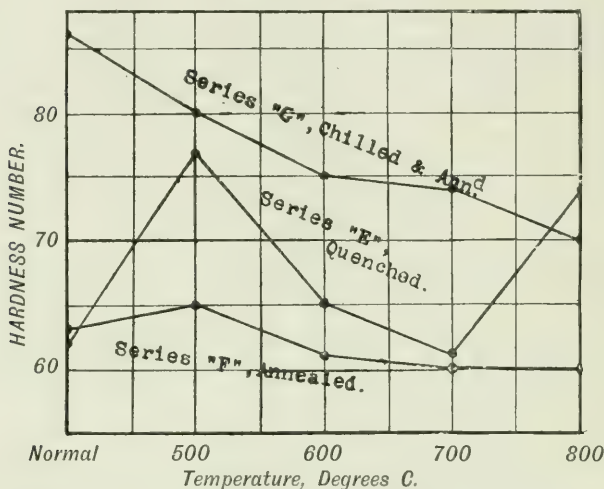


FIG. 6A.—Effect of Heat Treatment on Hardness of Gun-metal.

CORROSION.

As the result of recent researches with the brasses and bronzes it has been shown that one most serviceable method of getting over the trouble of corrosion is to eliminate the presence of all eutectoid from the structure. This is accomplished by the addition of other metals in the production of proprietary "alloys"; whereas it would appear that gun-metal may be quite as immune from such trouble by the simple operation of annealing, whereby the eutectic is destroyed.

Further tests are in progress with the object of determining how far this surmise is realised in actual corrosion tests, and the results of these may form the subject of a future paper to the Institute.

The authors take this opportunity of expressing their warmest thanks to the firm of Messrs. G. & J. Weir Ltd., of

SERIES "E."

(Etched with Ferric Chloride.)

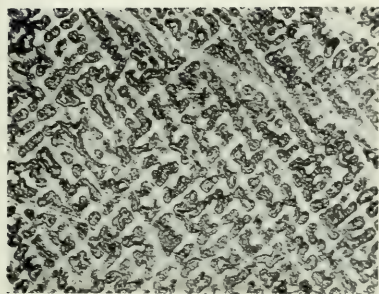


FIG. 7.—Bar E.D.N. V. 90 \times .

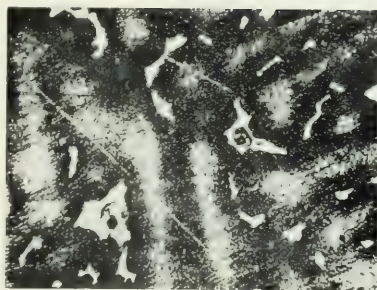


FIG. 8.—Bar E.D.N. V. 360 \times .

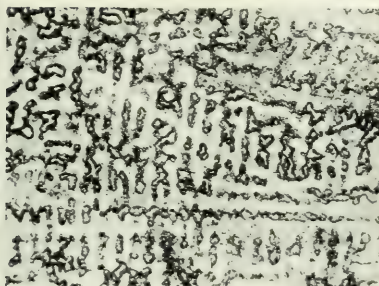


FIG. 9.—Bar E.D.Q. 5. V. 90 \times .

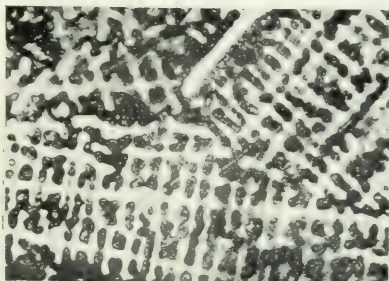


FIG. 10.—Bar E.D.Q. 6. V. 90 \times .

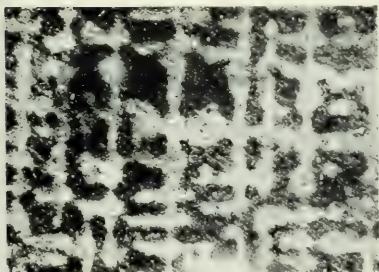


FIG. 11.—Bar E.D.Q. 7. V. 120 \times .

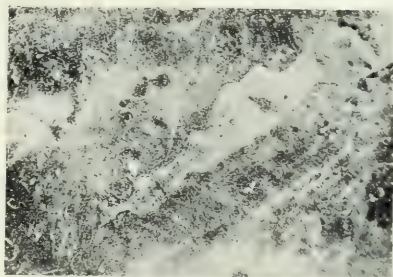


FIG. 12.—Bar E.D.Q. 8. V. 180 \times .

The photomicrographs have been reduced about one-half in reproduction.

SERIES "H."

(Etched with Ferric Chloride.)

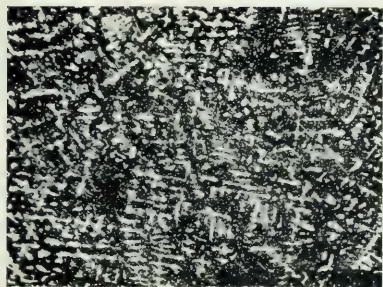


FIG. 13.—Bar H.C.A. 6. V. 90×.

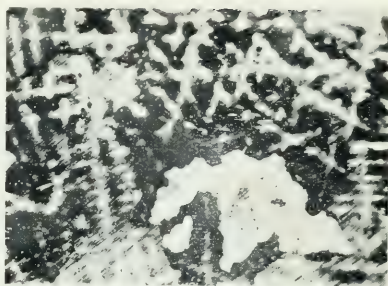


FIG. 14.—Bar H.C.A. 6½. V. 90×.

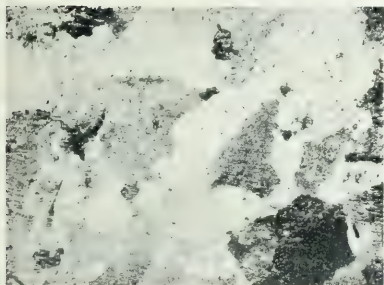


FIG. 15.—Bar H.C.A. 7. V. 30×.

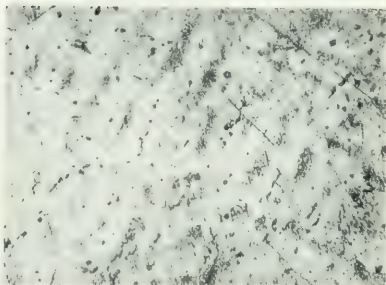


FIG. 16.—Bar H.C.A. 7. V. 270×.

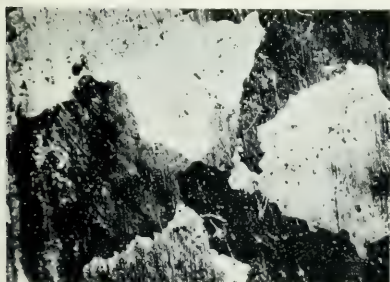


FIG. 17.—Bar H.C.A. 7½. V. 90×.

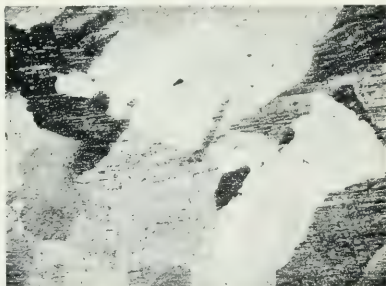
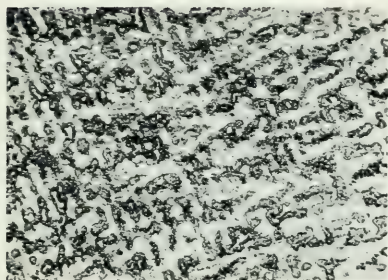
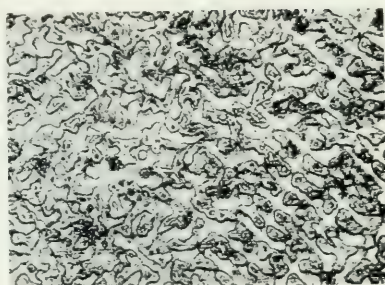
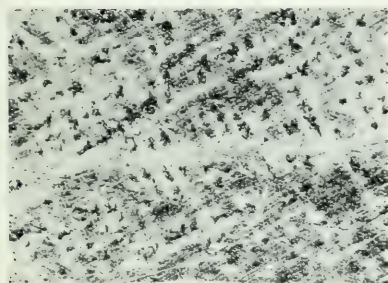
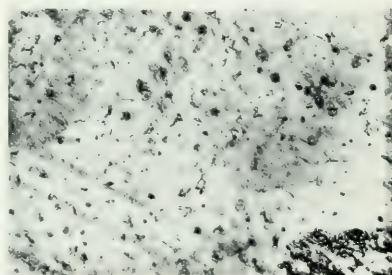


FIG. 18.—Bar H.C.A. 8. V. 40×.

The photomicrographs have been reduced about one-half in reproduction.

SERIES "F" AND "G."

(Etched with Ferric Chloride.)FIG. 19.—Bar F.D.A. 5. V. 90 \times .FIG. 20.—Bar F.D.A. 6. V. 90 \times .FIG. 21.—Bar F.D.A. 7. V. 90 \times .FIG. 22.—Bar F.D.A. 8. V. 90 \times .FIG. 23.—Bar G.C.A. 5. V. 90 \times .FIG. 24.—Bar G.C.A. 6. V. 90 \times .*The photomicrographs have been reduced about one-half in reproduction.*

SERIES "G" AND "K."

(Etched with Ferric Chloride.)

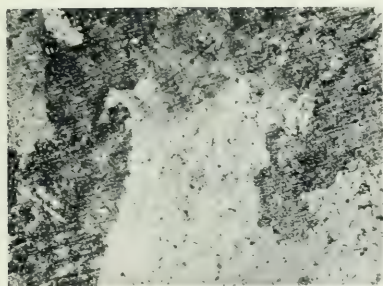


FIG. 25.—Bar G.C.A. 7. V. 90 \times .

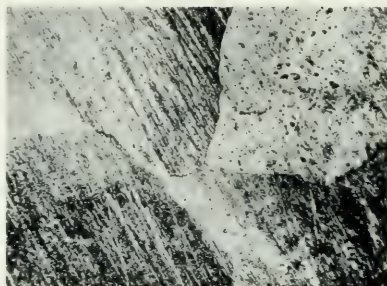


FIG. 26.—Bar G.C.A. 8. V. 90 \times .

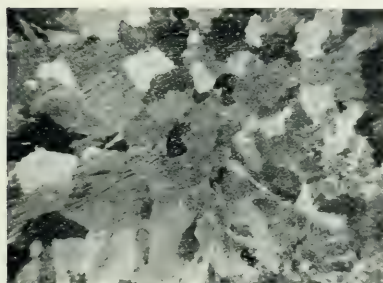


FIG. 27.—Bar K.C.N. O. 10 \times .

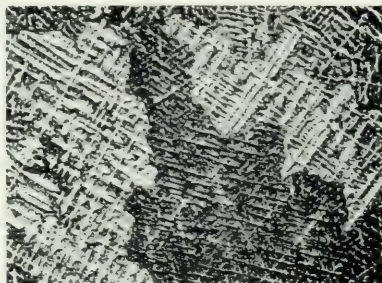


FIG. 28.—Bar K.C.N. V. 90 \times .



FIG. 29.—Bar K.C.A. 7 (XV.). V. 90 \times .

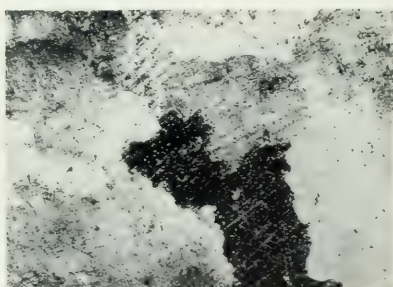


FIG. 30.—Bar K.C.A. 7 (LX.). V. 90 \times .

The photomicrographs have been reduced about one-half in reproduction.

Cathcart, for kindly granting the use of their extensive foundry and equipment in carrying out this research, and also for so magnanimously granting permission for the publication of the results, which the authors hope will have far-reaching effects in the practice of gun-metal founding.

SUMMARY.

The heat treatment of Admiralty gun-metal has been investigated by quenching and annealing bars cast in dry-sand and chill moulds. The treated metal was tested physically and examined microscopically.

1. The tests show that no improvement may be expected by quenching, which lowers the strength of the material.

2. Simple annealing of the metal for 30 minutes very considerably increases its strength and elongation, the maximum results being obtained after annealing at 700°C .

3. The homogeneity and other physical properties of the metal are correspondingly improved, but particularly the capability of the castings to withstand hydraulic pressure.

4. These results are considered to be due to the removal of the eutectoid from the microstructure, which after annealing shows only the crystals of α solid solution.

5. It is anticipated that this heat treatment will minimize corrosion difficulties.

NOTE BY AUTHORS.

The term "eutectoid" is a modified form of the more common term "eutectic," and is used to indicate a different origin of the characteristic structure. Thus a "eutectic" is formed by the solidification and decomposition of a liquid solution of two metals, whereas a "eutectoid" results from the decomposition of a solid solution.

DISCUSSION.

Professor H. C. H. CARPENTER, M.A., Ph.D. (Vice-President), in opening the discussion, was sure the members would regret the absence of the authors, who had presented a very interesting paper on the heat treatment of a particular type of gun-metal, the 88:10:2 mixture. It was obvious from the diagram in the paper that when the alloy was cast the range of freezing extended over at least 200°C ., with the result that the composition of the crystals, separating at any moment, differed from that of the liquid; and, diffusion not taking place to any great extent, there was a core structure in which there were layers of different composition. As a consequence, in the alloy as cast there was a mixture of α which reacted with the liquid at about 790° to form β , and that the β at a still lower temperature, rather below 500° , inverted to $\alpha + \delta$.

The PRESIDENT said that in the paper it was spoken of as a eutectic; ought it not to be eutectoid?

Professor CARPENTER said it was neither, as he was about to point out. Strictly speaking, it was what was called a peritectic reaction between the α crystals and the liquid of a particular composition giving the β . There was only one eutectic in the series, and that was at the extreme tin end of the diagram. It was not correct to speak of it as a eutectic. Accordingly in the alloy as cast there was, as the authors showed, a duplex structure. The whole value of the paper consisted in showing that if the alloy was annealed at a suitable temperature— 700° seemed to be the most suitable—very nearly the whole of the δ constituent dissolved in the α , and gave what appeared to be a homogeneous solid solution. For practical purposes he thought that might be regarded as an established conclusion. At the same time the curves which the authors gave on page 169 showed that, even after an hour's heating at 800° , there was still a good deal of δ left. Taking curve (*a*), on page 169, 1010° was the temperature of the liquidus. Then 765° was that of the peritectic reaction, and 455° was the temperature when α and δ were formed from β . On heating that, obviously 485° was the reverse of the 450° point. Then there came an inversion at 670° , which he was going to ask the authors to explain, and, finally, there was an inversion at 790° , which was the reverse of that at 765° . Curve (*c*) was that of a material which the authors said was annealed for sixty minutes at 800° . That was fully as long, in fact a little longer, than their treatment at 700° . It gave apparently the α crystallization, but nevertheless it would be observed that there was at 445° an inversion which was obviously the same as the 455° inversion in the first curve. That, he thought, meant that even so there must be a certain amount of the β constituent which had segregated, and which inverted to α and δ at that temperature. Those were somewhat scientific points connected with the paper. He would particularly like the authors to give their

view of the interpretation of the inversion at 670° on heating curve (*b*), because the reason for that was not clear, and they did not themselves advance any explanation. He thought the great practical value of the paper was that, with the comparatively simple and short-heat treatment of the alloy referred to, a material which, from the point of view of hydraulic castings, was apt to give unsatisfactory results, even when the metal was quite good, could be easily remedied. The root of the trouble was the long freezing range of over 200° , and theoretically it would be better, for that purpose, to use a different alloy with a very much shorter liquidus range. That was the reason why, in the research by Mr. Edwards and himself on the production of castings to withstand high hydraulic pressures, they found the copper-aluminium alloys very much better, because the freezing interval was comparatively short, and the difficulties due to a long freezing interval and the fact that equilibrium between the constituents was not obtained by diffusion were removed. Aluminium alloys had their own drawbacks. They were much more difficult to cast. From the practical point of view he thought the authors had quite established their case, that the very simple heat treatment at 700° was quite adequate in removing the difficulties which were due originally to the alloy being in a metastable condition.

Mr. E. F. LAW (London) said that Professor Carpenter had raised one or two points which were rather more theoretical than practical. Personally, he wished to raise one or two practical points and to issue a warning if possible. Gun-metal, as everyone knew, was used for a very large variety of purposes, and the structure of the gun-metal should be modified according to the purpose for which it was to be used. Raising the tensile strength and the elongation was not everything by any means. In the case stated by the authors, where the metal was intended to withstand hydraulic pressure, it was highly desirable that it should be uniform and homogeneous in structure. If, however, the method were used indiscriminately, and some gun-metal, which was to be used for slide valves or otherwise subjected to friction, was treated in that way the results would be disastrous. In gun-metal which was to be used for any purpose where friction came into play, it was necessary that the δ constituent should separate out. That was the essential feature of gun-metal as a bearing metal, and he thought it was important that the difference should be noted. They did not want the manufacturers to start annealing all their gun-metal castings irrespective of the purpose for which they were to be used, otherwise great trouble would be experienced.

Mr. ARNOLD PHILIP, B.Sc. (Member of Council), thought the paper, which he had read with great interest, was an extremely practical one. The very marked variations of the properties of the metal at 700° came out extremely strongly under the investigations which the authors had made, and he was sure the paper would be of very great value to the Admiralty engineering officials, who were using so many different articles

designed for many different purposes, but all made of that particular composition.

Mr. LEONARD ARCHBUTT (Member of Council) desired to say a few words to accentuate what Mr. Law had said. Many railway companies used for slide valves an alloy having not exactly the composition of the gun-metal referred to in the paper, but an alloy of copper and tin containing about 15 per cent. of tin. This alloy occasionally gave trouble owing to its brittleness. On the Midland Railway the valves were sometimes tested by putting them under a falling weight of 112 lb. with a blunt edge. The valve was supported on 9-inch centres, and the weight was allowed to drop across the middle of the valve. Valves cast in sand cracked almost invariably with the first blow from a height of 8 feet, and they broke in half with an average of about three blows. The effect of quenching them so as to prevent the separation of the δ constituent was tried. By that means the valves were toughened so much that they were found to withstand about four blows without cracking, and an average of about nine blows was required to break them. But the results from the point of view of wear were disastrous; they did not last anything like the length of time they did before—in fact, they wore away so rapidly that the process had to be given up. That showed, as Mr. Law had said, that it was necessary to consider the uses to which the metal was going to be put before deciding whether annealing was the proper thing to do or not. He had no doubt that for certain purposes it would be found extremely useful, and he thought they were much indebted to the authors of the paper for communicating the results of their experiments to the Institute.

Professor A. K. HUNTINGTON (President) thought the paper was a very useful one, as was also the point brought forward by Mr. Law and emphasized by Mr. Archbutt, that it was impossible to make the same gun-metal equally satisfactory for every purpose. It was a very valuable alloy which would by various treatments become useful for several purposes. With regard to the temperature of annealing, 700° was quite a reasonable temperature, and one which was not likely to do any harm; at the same time, when higher temperatures than that were used it was necessary to be careful. Experiments carried out on a small scale might be all right in themselves, but on larger masses of metal the outer portions were apt to be affected differently from the portions further in, and trouble might thereby be set up. The paper was an exceedingly useful one in many ways, and he was sure the members would wish to accord a hearty vote of thanks to Messrs. Primrose for it, and also to Messrs. Weir, who had allowed the publication of the various matters referred to in the Report. It was a very healthy sign indeed when manufacturers took up that attitude; it was one the Institute wished to encourage in every way—indeed it was one of the purposes for which the Institute was formed.

COMMUNICATIONS.

Mr. G. BERNARD BROOK (Sheffield) wrote that he would like to express his appreciation of Messrs. Primrose's paper. One point of considerable interest was noted on page 160, in which it was stated that "the test bars were not subsequently dressed or burnished, as this was found to interfere with the physical condition of the bar: *burnishing especially* imparted a skin to the metal which materially raised the tensile strength." He would be glad if Messrs. Primrose could give figures showing the relative strength of the burnished and unburnished bars. Was the effect common to all non-ferrous alloys? If so, would it not be wise to suggest a standard method for the preparation of all test-bars, so that concordance of results should be thereby assured?

Mr. G. BUTTENSHAW (Chorlton-cum-Hardy) wrote that there was little doubt that the annealing of castings made in Admiralty gun-metal might be said to break new ground in foundry practice as applied to the production of that type of casting; but, before such treatment could be universally adopted as a recognized part of the process of manufacture, it appeared necessary that yet further work should be done in that direction in order to obtain if possible results which would be sufficiently convincing to warrant the adoption of such treatment to castings to withstand hydraulic pressure. To make the reason of that statement clear one might ask, after carefully following the author's paper, what was the object of the proposed thermal treatment of Admiralty gun-metal? Evidently, from the remark on the first page, it was for the purpose of overcoming certain difficulties. With that in mind, he (Mr. Buttenshaw) examined section 2 of the summary, which claimed that "simple annealing . . . very considerably increases its strength and elongation. . . ." Turning to Table II. (page 164), which was the only one dealing with sand-cast bars, he did not find any extraordinary improvement due to annealing, except perhaps in the elongation after treatment at 700° C. That, of course, might be due to the fact that the normal cast bar gave a particularly good test; but he found, on page 171, two cases stated where bars, which failed to yield the required test, were regenerated into a condition approximately equal to that of the normal bar of Table II.; falling short, however, of the elongation obtained with bar F.D.A. 7 of that table. From that it appeared that if, for a certain reason, the alloy as cast, and before annealing, was not equal to the test required of it, it still seemed to retain an inherent deficiency of quality throughout subsequent heat treatment, so that, were the thermal treatment to be specified (as in the case of cast steel) with a proportionally raised test specification, such as would be justified by the claims to betterment of quality due to annealing as set forth in the paper, we should still probably find ourselves where we were. For example, the metal (page 171) which only stood 11 tons originally was raised to 15 tons only, due to annealing treatment. The point of all that was, was there not something more to be considered than the mere stepping

up, as it were, of both tests from their respective original positions by similar increments?

The writer's experience inclines to the view that there was, and as an instance he would draw attention to the fact that the tests given by the authors on the normal bars of Tables III., IV., and V. varied enormously (note G.C.N., H.C.N., K.C.N.), and it would be interesting to have some explanation as to the cause.

The most marked effect of annealing seemed to be shown in the cases where bars had been first cast in chills, and was what might have been expected, but it could not be supposed that castings were to be so cast; so that, unless it were intended to obtain results on test-bars which could not be taken as indicating the quality of the castings, the treatment in that form did not help to overcome the difficulties referred to on page 1. In fact, it might become necessary to suggest that all test-bars should have the inspector's stamp impressed on white metal let into holes drilled in the bars at the time of stamping, to insure that such treatment be not applied as a misuse.

Since reading the author's paper, the writer had looked up and selected a number of tests taken from bars cast in sand attached to castings for Admiralty work with which he had been concerned, the following being selected as some amongst the best obtained:—

Tensile Strength, Tons per Square Inch.	Elongation, per Cent.
17.04	17
17.44	15
17.4	15
18.2	20
18.4	19
18.4	20

The above figures were really as good, as regards tensile strength, as the annealed sand-cast bars of Table II., though possessing somewhat lower elongations. It might be asked in passing whether higher elongations were desirable in view of the variation to be looked for, in such cases, of yield point and Brinell hardness number. Referring now to No. 3 of the summary, which dealt with improved homogeneity, the writer felt compelled to suggest from past experience that such improvement could only be looked for to a very limited extent, although more light from the authors on that point would be of considerable value.

Considering for a moment the accompanying micrograph, Fig. 1, which was that of an Admiralty specified gun-metal containing 13 per cent. tin, but typical of similar cases of porosity with 88:10:2 gun-metal. That specimen was taken from the wall of a gun-elevating cylinder which showed slight leakage at 6000 lb. water pressure. The magnification was 240. What had occurred was further brought out in micrograph Fig 2, which was an alloy still higher in tin magnified 240 times; the micrograph having been used on a previous occasion by the writer to illustrate the porosity due to segregation. Did the authors consider that where such holes were produced, due to the action of gravity on

a liquid phase which had existed at some period during the slow cooling of a massive casting, that a subsequent annealing would produce sufficient diffusion to reconstruct the alloy as a homogeneous mass?



FIG. 1.—Unetched. Magnified 240 diameters.

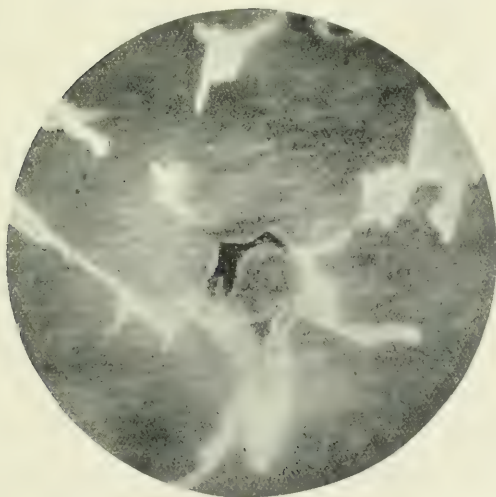


FIG. 2.—Heat-tinted. Magnified 240 diameters.

It had happened within the writer's experience that such a casting had been found to have a brittle whitish scale attached to the outside skin, the cause being that, during cooling, the casting had shrunk from

the sand wall of the mould while still at a temperature at which the eutectic internally was yet liquid. The eutectic (the portion shown light in Fig. 2) became exuded into the cavity between the casting and the sand mould forming the scale mentioned. This being an identical case with the first named case of porosity, would annealing completely reabsorb the scale! If not, it was reasonable to doubt its cure for the other case. Some of those troubles could be minimized by attention to pouring temperatures and a consideration of the effect of pouring on subsequent rate of cooling, but as a fact the cylinder previously referred to had to be made in manganese brass finally.

The writer might add that there was nothing like the difficulty of porosity from the above mentioned cause with the mixture used formerly more frequently, and composed of copper 87 %, tin 8 %, zinc 5 %, the objectionable β -constituent being almost entirely absent.

Mr. J. L. HAUGHTON, M.Sc. (Teddington), wrote that he had read the paper by Messrs. Primrose with very great interest, and was much impressed with the enormous increase, both in tensile strength and in elongation, which they had obtained by means of simple heat treatment. He considered that Figs. 2 to 4 were most interesting, inasmuch as they suggested that the net result obtained was probably a compromise between two reactions (as indeed was hinted by the authors on page 167), these being the growth of the crystal size and the removal of the α - δ complex. The first of these reactions tended to weaken the metal, and the second to strengthen it. It would be noticed that in all the graphs (Figs. 2 to 5) the tensile strength fell as the annealing temperature rose to between 500° C. and 600° C. That was to say, owing to the proximity of the 490° C. line on the equilibrium diagram, the tendency for the change $\alpha + \delta \rightarrow \beta$ to take place was small, whereas the crystals were permitted to grow. Above that temperature and up to 700° C. the $\alpha + \delta$ was being absorbed by the β , and, although the continued crystal growth tended to weaken the material, yet the removal of the hard and brittle δ far more than outweighed this, and a large net gain of strength was the result. When all the δ was removed, the crystal growth effect was free to show itself once more with a resulting weakening of the metal.

Fig. 5, however, he (Mr. Haughton) did not consider quite so satisfactory. In the first place, the change from 5-minute intervals to a 30-minute, and then a 90-minute interval, gave the maximum point at 30 minutes a much sharper appearance than it should have. Furthermore, he did not consider that, because, when annealing for 30 minutes the best results were got if the temperature were 700° C., and when annealing at 700° C. the best results followed the use of a 30-minute treatment, it was a logical deduction that 30 minutes at 700° C. was the best possible time and temperature. It was conceivable that, say 20 minutes at 800° C., or 40 minutes at 600° C. would give a better result. What was to be aimed at was the removal of all the δ , while at the same time the crystals were given the smallest possible chance of growing.

The writer also found great difficulty in accepting the authors'

explanation of the peculiar arrest at 670° C. on the heating curve (curve *b*, Fig. 6). Through the courtesy of Mr. F. Johnson, of the Birmingham Technical School, he was enabled approximately to confirm this arrest (he obtained two arrests at 620° C. and 680° C. respectively), but if the $\alpha + \delta \rightarrow \beta$ change was not complete at 490° C., there seemed no reason why it should cease absolutely until a temperature of 760° C. was reached, and then be completed suddenly. It would be of interest to see if a similar arrest would be obtained with the corresponding alloy made of pure copper and tin only.

There remained two minor criticisms which he (Mr. Haughton) wished to make. The first was that the absence of any analysis of the alloy was regrettable, the other was as to the employment of the term *eutectic* for the δ substance. It certainly was not an eutectic. The term *eutectoid* might be permissible, but he personally preferred Heycock and Neville's term "complex."

Incidentally the paper brought out the fact that the limit of saturation of pure α as fixed by Shepherd and Blough was more correct than that given by Heycock and Neville.

Mr. F. JOHNSON, M.Sc. (Birmingham), wrote that he had taken a great deal of interest in reading the paper, which contained information of a most valuable character both from the scientific and from the practical point of view.

The practical results bore out in a remarkable way what a study of the equilibrium diagram taught one to expect.

The influence of such a small proportion of zinc as was contained in Admiralty gun-metal in so drastically affecting the quenching properties was extraordinary, converting what was otherwise beneficial into a most harmful treatment.

Had the authors considered the question of a more prolonged heat treatment between 600° and 700° C. before quenching?

They did not state how long the bars given in Table I. had been kept at the reheating temperature before quenching. Judging by the micrographs, it seemed as if insufficient time had been given for the attainment of equilibrium. Possibly the zinc operated in retarding diffusion and attainment of crystalline homogeneity; the results of the half-hour annealings seemed to confirm this.

There was no doubt that zinc remained dissolved in copper at the expense of tin; this being particularly noticeable in α brasses containing tin, as the writer had pointed out.*

In comparing Admiralty gun-metal with gun-metal in which copper and tin were in the same relative proportions but from which zinc was absent, the writer had found a marked difference of structure between the two alloys (sand-cast under exactly similar conditions). The presence of zinc seemed to produce a more pronounced dendritic structure, the primary copper-rich crystallites being more continuously linked up than in the zinc-free alloy. In the latter alloy, too, the

* *Journal of the Institute of Metals*, No. 1, 1912, vol. vii. p. 201.

α - δ complex or eutectoid existed in larger masses, being readily distinguishable at a magnification which was insufficient to resolve the same constituent in the Admiralty alloy. That greater prominence of the brittle δ constituent and its greater intercrystalline continuity would explain the greater weakness and general inferiority of the zinc-free bronze as compared with Admiralty gun-metal.

Therefore, in alloys of that class it was necessary to aim at producing a structure in which the strong, tough constituent (primary α crystallites) exhibited continuity and the brittle constituent (δ phase) discontinuity. This influence of zinc would be particularly noticeable in such an alloy as Admiralty gun-metal, which lay so near the saturation boundary of the α phase field.

The writer regretted that, in view of the importance of the authors' results for future reference, they had omitted to give the analysis of their test-bars.

Throughout the paper, the authors used the word *eutectic* to describe what he (Mr. Johnson) preferred to regard as *eutectoid*, since its formation had occurred after the alloy had completely solidified and not during solidification.

On page 10 the authors, in describing Fig. 21, Plate VII., referred to small dark spots as representing lead which had been thrown out of solution at this temperature (700° C.). The writer did not agree with this view, since the insolubility of lead in bronzes and brasses was notorious, and although the process of annealing might lead to a coalescence of the lead particles, it did not throw out of solution a metal which had never existed in that state; moreover, no figures were given for the proportion of lead present.

In conclusion, the writer wished to thank Messrs. Primrose for having brought before the Institute a paper of such importance, and he thought, with them, that founders would have every reason to appreciate their efforts.

Dr. ROSENHAIN, F.R.S. (Member of Council), wrote that he had read the paper of Messrs. H. S. and J. S. Glen Primrose with considerable interest and pleasure. He was particularly concerned with the question of the porosity of metals and alloys, and was very much surprised to find, that in the case of gun-metal castings the authors were able to find visible shrinkage cavities in the material associated with porosity. He felt, however, that a little further proof was required before their conclusions on this point could be fully accepted. In the first place it would be necessary to show that the holes observed by Messrs. Primrose in their sections really were shrinkage cavities, but that was a matter which could only be convincingly shown to a third person by actual examination of the specimens themselves. He would therefore accept the view that they really were shrinkage cavities. It remained, however, to prove that these cavities were sufficiently continuous to permit of the percolation of water, while it was further surprising to find that annealing alone without mechanical working could cause these

cavities to close up completely. The proof that these cavities really formed the path by which liquid could percolate through the metal might perhaps be obtained by forcing a molten wax, pitch, or some similar substance, through the metal under pressure, and on allowing it to cool to cut cross sections. If the solidified liquids were found in the cavities described by Messrs. Primrose, the matter would be definitely settled. As the evidence at present stood, it seemed quite possible that the real seat of the percolation might lie elsewhere, and that possibly the shrinkage which gave rise to these cavities also gave rise to a certain looseness of structure which would allow the liquid to percolate through very much finer but more numerous channels between the crystals of the alloy. That such finer pores may be closed by the process of annealing alone appeared to him more credible than the closing up of a continuous system of cavities such as those shown in the micrographs of the present paper.

Mr. H. J. YOUNG (Wallsend-on-Tyne) wrote that he would like to ask whether the authors considered it would be practically successful similarly to heat-treat gun-metal containing appreciable quantities of lead, say one to three per cent. It seemed probable that the lead would "ball up" sufficiently to be a serious consideration, and since commercial gun-metals often *did* contain added lead the point was of considerable interest, and the behaviour of the lead during the experiments might throw light upon the question.

THE AUTHORS wrote that they were gratified that their paper had evoked so much interest, and regretted very much that circumstances had prevented their presence at the meeting. They had thereby had to forego the pleasure of replying verbally to the points raised in the discussion, and of thanking the members for their most appreciative criticisms. They had taken the liberty of amending one matter in their paper as now reproduced, and that was by substituting the term "eutectoid" for "eutectic" throughout. Some writers still used the latter term, but undoubtedly the former was the correct one if the definition they had appended as a note was accepted.

To Professor Carpenter they were obliged for the valuable contribution to the theoretical side of their paper, which was not intended to do more than record the results of practical work. As to the inversion at 670° which they had observed, they had already advanced the suggestion which appeared the most probable, viz., that this halt marked the completion of the $\alpha + \delta$ to β change. After the sixty minute annealing it was evident that the temperature at which the β formation commenced was lowered to about 640° , and the recalescence was less powerful than the original inversion at 756° on cooling from fusion. The final decomposition to $\alpha + \delta$ was also slight, as indicated by the curve (c). All three cooling curves had been obtained with the same mass of metal, and the peaks might therefore be taken to represent the relative intensity of the heat absorptions or evolutions.

They quite agreed with Mr. Law that it would not do to anneal gun-metal indiscriminately for every purpose. As a rule it was customary to have in gun-metal for bearings a little more tin than was permissible in the ordinary Admiralty composition, 88-10-2. A very hard bearing surface could be obtained by chilling gun-metal, but this was apt to induce a dangerous brittleness, unless the bearing was heavy enough to have a backing of comparatively slowly cooled metal.

Mr. Archbutt had referred to a bronze with 15 per cent. of tin, but this was considerably different from Admiralty gun-metal, in so far as the eutectoid structure was continuous, forming a ground mass with α -crystals embedded in it, whereas in gun-metal the eutectoid areas were usually surrounded by the α -crystals. Instead of quenching this bronze it might have been found serviceable to chill the bearing face of the slide valves. It is remarkable that in a paper on "The Wear of the Bronzes" presented by MM. Portevin and Nusbaumer at the International Association for Testing Materials, they show in a graph the diminution of wear caused by quenching a 0.015 per cent. phosphor bronze (85-15), and they remark that the elimination of δ marks the minimum wear of the bronzes which they have studied.

Professor Huntington's caution as to the care necessary in annealing large masses of gun-metal was correct, as undoubtedly rapid heating of these would result in inequalities of structure. However, it was not common to have castings of gun-metal in which the thickness was so great as to require more than ordinary caution in the rate of heating or cooling.

Mr. Brook had asked for figures in regard to the effect of burnishing the test-bars. This, however, was not investigated fully, as it varied considerably with the amount of cold work produced on the surface of the bar. Thus a small section was more affected than one of greater diameter, and when punch marks were used the skin-effect was completely annulled, the test-pieces often breaking through the mark where the skin had been pierced. This effect would be common to all metals, but the question of standardizing was too wide to discuss.

Mr. Buttenshaw seemed to doubt the advisability of annealing gun-metal for hydraulic castings, but the authors were convinced that he needed only to give the method a proper trial to find that it certainly produced a remarkable improvement in the property of the cast metal, especially that of remaining water-tight under considerable pressure. The explanation of the variation noted by Mr. Buttenshaw in the normal test-bars of series G, H, and K was that these had been cast and allowed to solidify under very different conditions as explained in the paper. The figures in the tensile tests quoted by Mr. Buttenshaw were undoubtedly very good, but many founders found it exceedingly difficult to attain these with anything like regularity. The porosity due to segregation illustrated by Mr. Buttenshaw was a most interesting case, but only with very exceptionally slow cooling of a very large mass could the action of gravity on the different constituents produce such cavities. In the ordinary case it was most probable that the primary

crystals grew rapidly enough to entangle small areas of β which afterwards underwent inversion. The whitish scale was, no doubt, due to pouring at too high a temperature, and it was not likely that so excessive segregation could be remedied by annealing. The alloy 87-8-5 might be all that was claimed for it, but it would not be accepted as Admiralty gun-metal.

Mr. Haughton had given a most valuable analysis of the authors' results, and they were pleased to note he had confirmed the peculiar arrest in the vicinity of 670° . The microstructure certainly showed no trace of the β constituent after annealing to 700° , whereas there was some left after annealing to 650° . The halt at 670° on heating was much more noticeable than the recalescence at 640° on cooling after annealing, and the heat absorption at 790° evidently indicated the commencement of incipient fusion at spots of high tin concentration, as there was no corresponding halt after a 60 minutes annealing, which had brought about diffusion of the tin-rich portions, and produced greater homogeneity. Any heating which reached 800° was found to be bad for the metal, and the question of longer heating at a lower temperature than 700° was not feasible in practice where time was an important consideration.

Mr. Johnson had inquired about the effect of prolonged annealing before quenching, and this point had been investigated. The results of the tests were not conclusive, but they showed no marked improvement on those got after slow heating to the desired temperature in about half an hour, followed by quenching. The analyses of gun-metals used were only decimally different from the specified composition of 88-10-2, and the total impurity was in no case more than 0.2 per cent. This was almost entirely lead, which did not show in the normal microstructure of the metal as cast, but it was clearly seen in the annealed specimens. The specks might be due to the coalescence of the lead particles, but it was doubtful if sufficient molecular mobility was attained to allow of this. The specks were very small and isolated, although they appeared to be most numerous in localities where the eutectoid areas had been. The perfect structure indicated by Mr. Johnson was certainly that which was most desirable in sound castings, but under certain conditions of cooling gun-metal could develop a structure similar to the corresponding bronze. It was when this had taken place and the eutectoid structure showed continuity that defects manifested themselves under water pressure, and it was in the elimination of this trouble that the annealing process was most valuable.

Dr. Rosenhain's remarks in regard to the shrinkage cavities were most suggestive, and would be followed up with the object of testing his theory. Space had precluded the reproduction of any more photomicrographs, but the unetched microsections clearly showed the black specks to be cavities, and also showed the shallow drag markings where the lead segregates had been polished out of the metal. Inter-crystalline looseness had not been detected by the authors in any of the most defective structures, and the most satisfactory castings were those con-

taining isolated eutectoid areas. Whenever the casting temperature or rate of cooling had been such as to produce continuity of the eutectoid, then serious porosity was evinced under water pressure.

To Mr. Young's inquiry the authors could not make any definite answer, as in the metal used in their experiments there was less than 0.2 per cent. of lead. No doubt on annealing gun-metal with over 1 per cent. of lead the trouble he mentioned would be likely to result.

THE FOURTH ANNUAL DINNER

THE Fourth Annual Dinner was held at the Criterion Restaurant, Piccadilly, W., on Tuesday evening, March 11, 1913, Professor A. K. HUNTINGTON, Assoc. R.S.M., President, occupying the chair.

There was an attendance of guests and members numbering about 150, amongst whom were:—

- Mr. W. DIXON (*President, The West of Scotland Iron and Steel Institute*).
 Sir H. F. DONALDSON, K.C.B. (*Chief Superintendent, Royal Ordnance Factory, Woolwich Arsenal*).
 Sir J. ALFRED EWING, K.C.B., F.R.S.
 Mr. E. HALL-BROWN (*President, The Institution of Engineers and Shipbuilders in Scotland*).
 Colonel H. C. L. HOLDEN, C.B., F.R.S.
 Mr. E. HOOPER, (*President, The Institution of Mining and Metallurgy*).
 Dr. RUDOLPH MESSEL (*Acting-President, The Society of Chemical Industry*).
 The Hon. Sir CHARLES A. PARSONS, K.C.B. (*President, North-East Coast Institution of Engineers and Shipbuilders*).
 Professor W. C. UNWIN, F.R.S.
 Sir GERARD A. MUNTZ, Bart. (*Past-President*).
 Mr. G. A. BOEDDICKER (*Vice-President*).
 Mr. SUMMERS HUNTER (*Vice-President*).
 Mr. W. H. JOHNSON (*Vice-President*).
 Professor T. TURNER, M.Sc. (*Vice-President, Honorary Treasurer*).
 Mr. L. ARCHBUTT (*Member of Council*).
 Mr. T. A. BAYLISS (*Member of Council*).
 Mr. GEORGE HUGHES (*Member of Council*).
 Mr. W. MURRAY MORRISON (*Member of Council*).
 Mr. ARNOLD PHILIP (*Member of Council*).
 Mr. L. SUMNER (*Member of Council*).

The CHAIRMAN gave the toast of "His Majesty the King," which was drunk with musical honours.

THE LATE SIR WILLIAM WHITE.

The CHAIRMAN, before calling on the first speaker, said: I wish to refer to the very great loss we have incurred through the death of Sir William White. If it had come sooner the loss would have been greater still, but fortunately we are now so well established that even the loss of Sir William White is not so serious as it would have been at an earlier period. He did an immense amount for this Institution, more than anybody here, except those associated with him, can very well realize. Looking at it from his point of view, probably there is no other death he would have preferred himself, because he was a man who was a worker from the beginning and never spared himself at all; and I have not the

slightest doubt that he would rather have died in harness and in the way he did than in any other. That does not, of course, in any way lessen our feeling in the matter of our loss. The best memorial we can put up to him is to work in the interests of the Institution as he did, and put our whole faculties into it in every way we possibly can. The members of this Institution have pulled together, and I think there is every sign that they will go on doing so, and that the Institution will progress in a very rapid way, and become such as Sir William would have wished.

“THE INSTITUTE OF METALS.”

Sir ALFRED EWING, K.C.B., F.R.S., in proposing the toast of “The Institute of Metals,” coupled with the name of its President, Professor Huntington, said: I find myself tempted to remark that of the making of learned societies there is no end. It seems an ungracious reflection on the part of a guest at a pleasant banquet like this, but one may confess to a certain amount of sympathy with the attitude of the ordinary layman, especially the commercial man, towards the scientific expert. The scientific expert, in one aspect at least, is a confounded nuisance; no sooner does a process of manufacture take a reasonably well stereotyped form, no sooner does the manufacturer settle down comfortably in his arm-chair to watch his growing bank balance, than the expert causes the process to become obsolete. Then again, he is always from a scientific point of view, enlarging the boundaries of knowledge; and the ordinary person, even the man with scientific sympathies who tries to keep up with new developments, finds himself panting a long way behind; he is out of touch with the new-fangled ideas of the specialist; he has to acquire, as it were, the alphabet of a new language if he would understand the terms which come trippingly from your specialist’s tongue. I suppose we must reckon with this as an inevitable result of that process of extreme specialization which we see going on all around us. It makes one scientific man almost unintelligible to another; it makes all scientific men unintelligible to students. Lord Rayleigh was telling a story the other day of a highly intelligent student of science who went to attend a lecture by a most eminent specialist. He came back and said, “The Professor gave us an hour and a half to-day”: his friend said, “What was it all about?” and the student replied, “He did not say.” And when you get this expert, he is like the evil spirit in the parable: he takes to himself seven others worse than himself, and they form a new society. You must join their blessed society or else get left, and then you find yourself poorer by a few more annual guineas, and you must clear another shelf of your bookcase to receive the volumes of their proceedings and transactions, that are dumped on you by a persistent post-office. I have done with grumbling now. There is, after all, another side to the picture. As Professor Huntington told you to-day in his Presidential Address, the members of such a Society as this are kindred spirits joined in a common aim. Their combination has a most valuable effect in stimulating their study of the subject; it is immensely helpful not only to them individually, but also to the progress of the subject

itself. You, gentlemen, as a Society, are the offspring of a science which is tremendously alive—a science and an industry that is undergoing a prodigious growth. Your vitality as a Society reflects the vitality of the industry and the science with which you are connected. Let them stagnate, and you would dwindle. On the other hand, your corporate energy furthers their progress. You are only in your fifth year, and what a lusty youngster you are! You have over 600 members; you have formed provincial branches; you have appointed various active committees, one of which discusses such questions as why the rust doth corrupt; and another tries to formulate the exact terms which are to be used in the expression of your new ideas. Your subject is one that possesses an extraordinary fascination—a fascination I know well. If I may venture on a personal note, it was my own last scientific love ten years ago before I suffered what Shakespeare calls a sea change. It may interest you perhaps to know how I began the study of metals. It was about fifteen years ago that an advanced student came to me—I was then a Professor in Cambridge—and he said he wished to carry on some work in research. What a Professor has to do in such a case is to look as omniscient as possible, and to suggest subjects of research to the student. I said: “There is rather a newish subject, which I believe is promising; people polish up metals, and look at them in the microscope. I do not know anything about it myself, but I should like to learn something about it; so let us take it up and learn it together, and I think there is a good chance that we will find it open up various roads to discovery.” Well, we found it was so: that student was one whose name is extremely well known in this Society, Dr. Rosenhain, one of your most actively productive members, who was recently elected to the Royal Society for his researches on metals, whose absence from this gathering we much regret to-night.

You have been extraordinarily fortunate, gentlemen, in your selection of Presidents. Who can say what the Society owes to the wide knowledge, the ready tongue and pen, the untiring energy, and the unfailing sympathy of its first President, Sir William White. It saddens us to think that his genial presence is lost to us and to the many other kindred societies which to-day are mourning his death. In your most recent President, Professor Gowland, you had a distinguished metallurgist, with whom I may perhaps claim to have had a very slight bond; my first appointment as a Professor was to the University of Tokio in Japan, and it was my privilege at the end of each month to receive a roll of the most beautifully minted gold coins which I have ever seen anywhere; these coins came from Professor Gowland’s mint. In your new President you have a gentleman who was a metallurgist when for the most part we were in what may be called our metallurgical swaddling clothes. I think he may fairly claim, as a Professor of Metallurgy, to be a lineal descendant of the oldest professor of whom we have any record—I mean, of course, Tubal Cain, the seventh from Adam, who, we are told on the best authority, was the instructor of every artificer in brass and iron. But Professor Huntington is not satisfied with the furnace; he is not

even satisfied with the ashes, for, phoenix-like, he rises from them into the air. I had almost called him a prince of the power of the air, but I believe that term is used by theologians in a somewhat disagreeable connection. Professor Huntington has at least this analogy to the other gentleman, that when he does exercise his dominion over the air, he is accompanied by an attendant "gnome." We may safely say that he is "in the first flight" of metallurgists. He has taken a house, I am told, near Eastchurch, for the purpose of pursuing his practical studies in aviation. It was only the other day that he made successful flights there in an aeroplane of his own design. We cannot but hugely admire his skill and his courage, and we will wish him many happy returns to earth. Gentlemen, I give you the toast of "The Institute of Metals," coupled with the name of your genial and plucky President, Professor Huntington.

Professor A. K. HUNTINGTON, Assoc. R.S.M. (President), in responding to the toast, said: It is very "rough" on your President to have to follow on such a past-master in after-dinner speaking as Sir Alfred Ewing. I do not know any more difficult task, and I think you will all agree with me. Personally I always look upon an after-dinner speaker as born, and not made, and when I have to make an after-dinner speech I always wish I had not been born, or, in the alternative, that the speech had been made. I have already occupied your time and your patience very much this afternoon, and I do not propose to inflict very many words on you this evening. I took you through the past history of all the Institutions that ever were, I think, and I hope that we received some encouragement at any rate from their performances in comparing them with our own, and that we received encouragement as to our prospects. I will not bore you with statistics after dinner; they are very indigestible things; but it is quite clear that we occupy a position to-day as good as has been occupied by similar institutions—in fact better—and I think that we owe that to the real want that existed for this Institute, though that in itself would not account altogether for our success, for there might be the want, but we might not be capable of properly filling it; but we have made such a good start in the matter under our previous Presidents, that I think it would be a disgrace to us now if we did not succeed in a very marked way.

It only remains for me to thank Professor Ewing for the kind way in which he has spoken of the Institute, and incidentally of myself, and to hope that we shall see him here again on some future occasion to give us such a lively and interesting address as he has just given us.

"KINDRED SOCIETIES."

Sir GERARD MUNTZ, Bart. (Past-President), in proposing the toast, "Kindred Societies," said: When I became Past-President I thought that I was going to take a back seat and have a quiet time, and for over a year I succeeded in doing so. I was able to sit down and enjoy

my dinner, and not suffer indigestion from anxiety because I knew I had to speak ; but this year unfortunately, at a weak moment, I went to the headquarters of the Institute of Metals, and while there the Secretary came to me and inveigled me to fall back into my evil ways, and consent once again to talk. The toast entrusted to my care to-night is that of "Kindred Societies." When I had this toast placed in my hands I was not at all sure that I was going to do justice to it, and I am less sure now, after the remarks of Sir Alfred Ewing, because he began with the remark that, "In the making of learned Societies there is no end," and that appeared to me to be not altogether propitious to a toast of this nature, because we happen to be the last Society, or the last Society of any note, and it appears to me to be rather audacious on my part to talk about Kindred Societies. In my instructions on the subject the Secretary was good enough to send me a partial list of Institutions which would be represented here to-night. We have represented here at least seven Institutions of much older standing, and of much greater importance, and of much larger membership than ourselves ; and to get up and propose "Kindred Societies" makes one feel something like I did in my early school days when at Harrow, and I went to Lord's for the cricket match, and talked about "Wz." Sir Frederick Donaldson represents one of the Kindred Societies. He is President of the Mechanical Engineers, with whom I have the honour of being associated, whose membership is more than ten times our membership, and whose years are many more than are those of this Institution. There are other gentlemen in the room representing the other six Societies whose Institutions are far greater than ours, far older than ours, and, therefore, I feel, as I said, that there is a certain amount of audacity in getting up and talking about Kindred Societies. On the other hand, they are Kindred Societies, because although we are new and young, and have only five years of life, we are interesting ourselves in the science of metallurgy in which many of those Societies are also interested, and one of them includes the word "Metallurgy" in its name. Even those who do not include it in their name include it in the Papers which are read at their Institutions. You may take Marine Engineers and Locomotive Engineers—any kind of Engineering Society which exists: it is interested, and cannot help being interested, in the work of the Institute of Metals ; and, therefore, I feel that we are to some extent, although the latest child of all, kindred to those Societies. Sir Alfred Ewing would refer you to the scientific expert. He was not polite in his comments on the expert, and I will not go back so far as to remind you of how the late Sir Frederick Bramwell described a scientific expert. I daresay some of you will remember it, but nevertheless a scientific expert has his uses. I am not a scientific expert, but only a manufacturer who suffers from a scientific expert. The scientific expert does make a barndoor manufacturer think, and occasionally he helps him in so far that he puts his spoke in the wheel of the third member of our Institute, the user. The user is a very peremptory person ; he is very arbitrary ; he knows everything as a rule long before we do ; and, therefore, we have to be

careful, and our only chance is to get behind the scientific expert, and get him to protect us from the wrath and attack of the user ; so the poor scientific expert, though often abused, has his advantages to a certain extent.

To come back to my toast of "Kindred Societies," I feel that we are much honoured to-night in having such a very strong representation of these Kindred Societies. I will not name the Societies, and I will not name the gentlemen present ; I will spare their feelings if I can ; these Societies are very well represented by our distinguished guests here, and I do feel that this Institute would be grateful for these gentlemen coming here to-night to support the child of the Institutes, and I can only hope that although, as Sir Alfred has said, "To the making of Institutes there is no end," that that may not stop other Institutes from starting. It is the hope of all small boys at school and young members of a Society that boys and members younger than themselves will come in so that they will not be the last in the class : and so I hope other Societies to which we shall wish all success will follow us so that we shall not be the junior. Gentlemen, I have the pleasure of giving you the health of the Kindred Societies, and I have to couple with it the names of my friends Sir H. F. Donaldson and Mr. E. Hall-Brown.

SIR H. F. DONALDSON, K.C.B. (Chief Superintendent, Royal Ordnance Factory ; President, the Institution of Mechanical Engineers), in responding, said : I am feeling extremely honoured that upon me should have fallen the task of responding to this toast. I can only wish that it had been entrusted to other hands more capable, and to a tongue more ready than mine. I see that I am to share the responsibility of reply with another, and that that other comes from the north of the Tweed. He will, I am sure, pardon me if, when I ask what really is included by Kindred Societies, I quote an incident drawn from Scotland, where relationships are comprehensive, to show that it is a very wide area over which I might travel. The incident occurred in connection with a rich American, who took a large house in Scotland. He took a large family party with him, and he took all their household gods with them ; among the household gods he took an ape, but the ape did not like the climate and so it died, and he instructed the gardener to bury it. The Scotch gardener does not take kindly to burying monkeys, and so he chucked the corpse on to the peat hag. Two gillies came along and saw something lying there, and one said to the other : "What's yon ?" The other said : "Ah dunna ken—he's ower hairy for a Campbell ; he's ower short for a MacDonald. Awa' doon to the lodge, and see if it's one of them American bodies." The gillies on the Scotch moor thought they recognised kindred, though they failed to place the relationship. You will, I think, agree that if we are to include in the Kindred Societies, whose health you have drunk, the simian tribes—well, I am afraid I cannot respond for them ; but I can, and do respond most readily, and most thankfully, for the very kind words in which this toast has been proposed by Sir Gerard Muntz, who assumes an unduly retiring position

when he places himself in the lowest form at Harrow and gazes with longing eyes at other societies a few years older than this one. He is himself on the highway to high position in other societies, so that he is looking forward with—shall we say reasonable hope?—to having days of added dignity, if not of ease. He said he does not like speaking, but he does it so well that I am sure we can put up with his dislike. Gentlemen, I am being discursive to a degree. I really am to respond for the toast of the Kindred Societies. I have thanked you for the kind way in which you have received and drunk the toast, and I can assure you that Kindred Societies regard the growth of this Society with the utmost pleasure, as showing the desire there is for specialized study to forward, through the discoveries of the present day, the interest and advantage and place them in the hands of those people whom Sir Gerard Muntz regards with such disfavour—the users. Gentlemen, I thank you very much, and I should very much like to end up with another little story, but I have been told that we are in the middle of Lent, and that if I told another story it must be a fish story. Gentlemen, I have not got a fish story; I have always tried to be, and I have regarded myself, and I hope with some justice, as a truthful man. I am not, therefore, going to tell you another story. I tell you the truth, and I say we of the Kindred Societies all thank you for the honour you have done us.

Mr. E. HALL-BROWN (President of the Institution of Engineers and Shipbuilders in Scotland), who also responded, said: I have to thank Sir Gerard Muntz for the very kind way in which he has proposed the toast of “Kindred Societies,” and you, gentlemen, for the very hearty way in which you have honoured that toast. It is at all times a difficult thing for a modest man to speak in company, and Sir Gerard Muntz might have been expressing my own feelings when he disclaimed any right to pose as an after-dinner speaker. I am, nevertheless, very pleased, Mr. President, to join in the reply to such a heartily honoured toast. I should have been happier, I dare say, had I not been asked to reply to any toast at all; but as it is, I can assure you that we of the Kindred Societies, which have been so highly spoken of by the proposer of this toast, feel highly honoured in being asked to accept the hospitality of your board, and to enjoy with you the pleasant evening which we have spent together.

Something has been said of the youth of this Society, but youth is not always a bad thing. I seem to remember something of a Scotsman who was asked how he would like a wife of fifty, and he replied he would rather have two of five-and-twenty. In the case of the Institute of Metals, youth is no disparagement; I can think of no other institute which for the time it has been in existence has done so much good work. I am sure the Kindred Institutions must be proud of this youngest relative. We have a song in Scotland entitled “We’re a’ John Tamson’s bairns.” I do not know that John Tamson was any relative of Tubal Cain, that celebrated Professor of Metallurgy of whom we have been hearing, and so I am unable to connect the two names; but the

idea expressed in the Scottish song is that which should, and I believe does, animate the whole of the Kindred Institutions, and accounts for the friendly feeling which prevails amongst them. We may all work on different lines, some ferrous and some non-ferrous, and some of us indeed may not know whether some of the metals we use are ferrous or otherwise; but we are all trying to make the art in which we are engaged, and the science by which that art is directed, a little better when we stop than it was when we began. This Society of yours, of which I am pleased indeed to be a humble member, if it is young—and it is—at any rate has this proud boast, that it is concerned with the making of the materials with which the others have to work. It is a fundamental Society, and the work that it does must go to the foundation of the whole structure. A sound knowledge of the materials with which we work is the foundation upon which, and upon which alone, the best work can be done. Therefore, I think it would indeed be false modesty for this Society to hide its head. It must know of its own importance, which is thoroughly recognized by every scientific society in the land—I believe by every scientific society in the world.

I do not know that the last speaker's story about Scotland was very flattering to my national feelings. I have, however, a lingering suspicion that Sir F. H. Donaldson slightly modified the story to save the susceptibilities of the audience to which he was delivering it; but never mind, whether the deceased was supposed to be an American or a native of the land which is usually described as lying south of the Tweed, it does not in any way detract from the humour of the story.

Gentlemen, in conclusion, I desire to repeat that it has been indeed a great pleasure to me to be here, and I am sure that our Institution appreciates the invitation which we have had the honour to receive from you fully and highly.

“THE GUESTS.”

Professor T. TURNER, M.Sc. (Vice-President and Honorary Treasurer), in proposing the toast said: The toast that has been entrusted to me is one which I am quite sure every member of this Institute will drink with enthusiasm. It is that of “Our Guests.” As you know on an occasion of this kind we have the advantage of meeting old friends and also very often of making new friends; that is one of the objects of a gathering such as this. To-night we meet under somewhat chastened circumstances. We have already had reference to the loss which our Institute has sustained by the death of our first President, and unfortunately our Council to-night is very small in number, for we have apparently an epidemic of sickness among the members; but fortunately I believe in every case the indisposition is of a kind from which we may hope the members may soon recover. At the same time we do miss to-night the faces of members of our own Council who have taken an interest in this Institute since its formation. We desire to thank the guests, the distinguished guests, who have come to us this evening because we recognize that their presence is an expression of sympathy with our aims and

of interest in our work. The guests represent different branches of practical work, and especially different branches of engineering. Several of these we have already had the opportunity of hearing with much pleasure. Among the guests are included Sir H. F. Donaldson, who spoke to us but a moment ago, and Mr. Hall-Brown, who represents the Institution of Engineers and Shipbuilders in Scotland. Also is included our old friend Sir Alfred Ewing, whose brilliant May lecture is one to which we listened to with great interest, and which the majority of us have read with much profit. We have also present to-night Mr. Hooper, the President of the Institution of Mining and Metallurgy, a closely allied institution, whose progress we can only envy, and whose work we can endeavour to some extent, at all events, to follow. We may hope that our Society may in time become as important as theirs. We have also a representative of the Iron and Steel Institute in the person of its Secretary, Mr. G. C. Lloyd. We have, too, the acting-President of the British Foundrymen's Association, Mr. J. Oswald. We are glad to see again Dr. Messel, who spoke to us on a previous occasion, and who is the acting-President of the Society of Chemical Industry. We have also with us Professor Unwin, a Past-President of the Institution of Civil Engineers, who, I believe, spoke to us on a previous occasion, and whom we are very glad indeed to have as a guest supporting us to-night. The two gentlemen who are to respond to this toast are known throughout the whole country, and far beyond the limits of the United Kingdom. We have on the one hand Colonel Holden, who after serving his country in India for some years returned to England, and for a number of years occupied the important position of head of the Royal Gun and Carriage Factory at Woolwich. I do not know that he is not better known in our country, however, as the designer of the Brooklands track, which we had an opportunity of visiting last autumn; many of us, I have no doubt, had been there many times before, and a few of us had an opportunity of going round that track, and we enjoyed the trip very much. He is now connected with the Ordnance Board, which, of course, is a very large user of non-ferrous metals, and a director of certain companies, including, amongst others, one of which the Midlands is proud, the well known B.S.A., which again is a user of metals in all shapes and forms, including, of course, the non-ferrous metals. We appreciate his presence, and we welcome him among us, and hope that we may see him on very many future occasions. Then we have to respond to the toast also the Hon. Sir Charles A. Parsons. I cannot gather whether we should regard him as a visitor or not. He is one of the members of our own Society, one of our earliest members; and those of us who were present at the Newcastle Meeting about two years ago will remember how successful that meeting was, and how admirable all the arrangements were that were made for our comfort and for our pleasure. Sir Charles Parsons on that occasion acted, I believe, as Chairman of the Local Committee, and took a very active part in connection with those arrangements of which I have spoken. But he comes to us to-night as representing the North-East Coast Institution of Engineers and Shipbuilders, and we are glad, there-

fore, to welcome him as a guest. For me to endeavour to tell you of the achievements of Sir Charles Parsons would be only to tell you what all the world knows. The turbine, with its wonderful applications, will always be associated with the name of Parsons. I believe he is interested, and has been interested for a long time, too, with other subjects of a scientific character, including even the production of the diamond. But these are only a part of a very full life and of the work of one who is essentially a hard worker, one who can turn the night into day, and do twice as much in the day as the average man can do. I am sure to-night we all welcome these guests not only on account of their own eminence in their particular professions, but because we feel that their presence is an incentive to the younger men amongst us, and that it is an advantage to our Institute to have them amongst us that we may have their support and their help. I, therefore, have very much pleasure in proposing to you the toast of our guests, coupling with that toast the names of Colonel Holden and the Hon. Sir Charles Parsons.

Colonel H. C. L. HOLDEN, C.B., F.R.S., in responding, said: There is a very old saying that there is more pleasure in giving than receiving. To-night I think that there is perhaps an exception to that old saying, an exception to the rule, and that is in the case of the guests; they are more pleased in receiving your hospitality, or at any rate quite as much pleased in receiving your hospitality, as you are in giving it. Several allusions have been made this evening to the Society being a young one, but I can tell you that many people, workers in other spheres perhaps outside this Society's work, have been from the first very much interested in it. The Institution has done a great deal already, but there is a great deal of work in front of it. To take only one section—one that at the present moment is uppermost at any rate in the newspapers, if not in the minds of the people—that is aeronautics, a subject in which we have already heard that your President is intensely interested. People who are interested in aeronautics are looking to you to provide something better in the way of materials than they have now. They are using at the present moment wood, iron, steel, and aluminium, in the construction of aeroplanes. What they are looking to you for, gentlemen, is to provide them with a metal which is as light, or even lighter than magnesium, as strong as steel, absolutely unbreakable, and absolutely unoxidizable. I can tell you, gentlemen, that the aeronautical people are not going to be satisfied until they get it from you. That is one of the problems you have to face, and the sooner you provide that the better for the country, and the better for yourselves. I feel that if I inflicted a long speech upon you this evening I should be entirely wrong. After me comes a gentleman who is justly celebrated not only in this country but throughout the world for his inventions, and for me to take up the time that would otherwise be occupied by him would be a mere impertinence on my part. I, therefore, beg to thank you on behalf of the guests who will again offer their thanks to you through Sir Charles Parsons. I beg to thank you for your hospitality and kindness to us to-night.

The Hon. Sir CHARLES A. PARSONS, K.C.B., F.R.S., who also replied, said: I scarcely know in which capacity to address you, whether as a guest, or whether as a member of this Institution. As a guest, I must thank you on behalf of the other guests and myself, for you have treated us royally to-night, and not only for the inner man, but you have provided a most admirable and interesting selection of Papers for to-morrow. One of the great advantages that has been mentioned to-night of this Institution is the sweeping away of the cobwebs which have surrounded for so many generations the non-ferrous metals and their treatment. If this Society succeeds in elucidating the treatment of these metals, and enables engineers to deal with them more successfully, it will have done a great work, and more than justified its existence. But the members have a further sphere, and a most wonderful sphere, before them. I was speaking to my neighbour Mr. Johnson to-night, and I was saying what a grand time people had in the time of Stephenson; they had all the engineering field before them; there had been little done; everything was new and fresh. This Institute has started in a similar position. I have before me a list of the guests here to-night. Mr. Hall-Brown, President of the Scotch Institution, who is interested in gas and oil engines, would, I have no doubt, like you to provide him with a metal which would stand gaseous explosions. The President would, I have no doubt, like a very strong metal for his flying machines. Mr. Siemens would like a tungsten wire that would stand a test of an enormous number of tons per square inch. Sir Frederick Donaldson would like you to provide him with a steel for guns which will not corrode or erode. I could go through the desires of many of the other guests. Personally I should desire if you could provide a metal for turbines which is non-corrosive and which has no coefficient of expansion. You have also a most interesting and important field in the rare metals, of which we know comparatively little. There seems to be an immense future for this Institution, and you ought to have a really grand time, like the engineers of old. Thank you, gentlemen, for the reception you have given us this evening.

BIRMINGHAM LOCAL SECTION.

A MEETING of the BIRMINGHAM LOCAL SECTION of the INSTITUTE was held on February 18, 1913, when Mr. C. H. WALL read a paper on "Annealing Muffles," Professor T. TURNER, M.Sc., being in the Chair.

The following notes constitute a *resumé* of Mr. Wall's paper:—

Reference was made to the old pattern of furnaces, with large fire-boxes, and the flame passing over a counter arch, across the metal to be heated, and away through side flues to the stack. The combustion in such furnaces was very incomplete, and the furnaces were consequently inefficient.

During the last ten to fifteen years annealing muffles, Mr. Wall said, had undergone great changes. The fireboxes had been reduced in size, the flues arranged along the sides and underneath the bed of the furnace, the heat thus circulating all round the muffle.

End fired muffles were still often used, but it was more usual, and generally better, to have them cross fired; two or three fireboxes being arranged along one side of the muffle, it being possible to build such muffles 50 feet in length. The flues were led backwards and forwards underneath the bed two or three times before reaching the stack.

Closed annealing muffles were suitable for certain classes of work, but the fuel consumption was rather greater than in the open type.

Gas-fired muffles were, when properly constructed, very efficient. It was possible to make such a furnace consuming only 1·7 to 2 cwts. of coal in the producer to heat 1 ton of metal. It was theoretically possible to use 1 cwt. fuel to 36 cwts. of iron heated to welding heat.

The efficiency of muffles was increased by heating the air for combustion.

In arriving at the efficiency of a muffle, a test should last at least a week or even two, and it should be conducted under ordinary working conditions.

For working muffles to the best advantage, pyrometers should be employed, a record being kept for each day's work.

OBITUARY

ARTHUR CROSIER CLAUDET died on January 17, 1913, at Hampstead, at the age of fifty-seven. He was educated privately, and at the Royal School of Mines. He became Assayer to the Bank of England and to the Royal Mint Refinery, and succeeded his father on his death in the business of A. C. Claudet, of Coleman Street, E.C. He was Honorary Treasurer since its foundation, and President in 1906, of the Institution of Mining and Metallurgy, and was an original Member of the Institute of Metals.

Engineer Rear-Admiral JOHN THOMAS CORNER died suddenly at Bad Neuheim, Germany, on August 4, 1912, aged seventy-three. Born at Sheerness in 1849, he entered for a special course of training at the Royal School of Naval Architecture and Marine Engineering, South Kensington, in 1868, where he took his fellowship degree in 1872. He joined the Royal Navy as an assistant-engineer in 1871, became an engineer in 1876, chief engineer in 1884, staff engineer in 1888, and fleet engineer in 1892. He was promoted to the post of Inspector of Machinery in 1899, and was made an Engineer Rear-Admiral in 1902. Admiral Corner was a member of the Admiralty Committee of Reference for Machinery Designs, 1891-1904, and of Admiral Buller's Machinery Committee, 1892-93. He invented a Whitehead torpedo dropping gear in 1875, whilst serving in the Mediterranean Sea as an Engineer, for which he received the Admiralty's commendation and a gratuity of £100. He was made a C.B. in 1907. In 1909 he retired from the Navy, and commenced practice as an engineer in Victoria Street, Westminster, besides serving as a Director of Bull's Metal and Metalloid Company, Limited, and of the Argyll Motor Company, Limited. Admiral Corner was elected a member of the Institute of Metals in 1910, and read a Paper on "Some Practical Experience with Corrosion of Metals" at the Annual General Meeting of the Institute in January 1911.

GEORGE MATTHEY died at his residence, Cheyne House, Chelsea Embankment, on February 14, 1913. He was a Member of the Legion of Honour of France, and of the Austrian Order of Francis Joseph, and received the Prussian Gold Medal for art and science. Mr. Matthey was a Vice-President of the Royal Institution from 1896-97, and a Fellow of the Royal Society. He had the added distinction of being the first Honorary Member of the Institute of Metals.

WILLIAM HENRY WHITE.

By the death of Sir William Henry White on February 27, 1913, in his sixty-eighth year, the Institute of Metals lost one of its most striking and brilliant personalities.

Sir William was foremost among those who were identified with the inception of the Institute. He became its first President in 1909 and was elected its first Fellow. Gifted with a facile pen and a trenchant and persuasive eloquence, his contributions to the Institute, as to other scientific and technical societies, were marked by a lucidity of expression and breadth of knowledge which placed them in the front rank of contemporary achievements; but Sir William's career as a Naval Architect necessarily makes the strongest appeal to all interested in technical pursuits.

He entered his Majesty's Dockyard, Devonport, by open competition in 1859, as a Dockyard apprentice, and if genius can be regarded as an infinite capacity for taking pains then he undoubtedly had genius. At a time when there were no technical schools, he as a youth culled information from all available sources. His industry and attainments won him an Admiralty Scholarship after serving as an apprentice for four years, and in 1864, after obtaining the first position in a competitive examination, he proceeded to the Royal School of Naval Architecture and Marine Engineering, South Kensington.

Here he stood foremost amongst his contemporaries, his originality and capacity for work marking him as one whose probable destiny it was to have a prominent future in the profession of Naval Architecture. On completion of his studies he was the recipient of the Diploma of Fellowship (first class) of the Royal School of Naval Architecture, and then proceeded (at the age of twenty-two) to the Admiralty, the Constructive Department of which was at this time under the direction of Sir Edward Reed. During this period of his career White showed that he was no pedant, and was always seeking to put to practical use ideas springing from the work of his earlier training. He may be said to have first come prominently into notice in the Department by his detailed work in connection with the Committee on Designs in 1871 and onward when he assisted that body, and more particularly Sir Nathaniel Barnaby, in making the detailed calculations involved in new ship designs especially as regarded stability. This work was characterized by such thoroughness that the Department quickly recognized in him one whose energy, knowledge, and resource promised early distinction.

In the year 1877 he published his "Manual of Naval Architecture," which, by its wealth of principles and facts, and easy literary style, has become a classic among text books, and has done more to raise the study of this science to its present high level than any previous work on the subject. In this book (revised in later years) White gave unstintingly of his laboriously acquired knowledge, and for this it may be said that every student of Naval Architecture is his debtor.

White's intimate association with two naval architects of such repute

as Sir Edward Reed and Sir Nathaniel Barnaby was no doubt of great advantage to him, and promotion came rapidly, for at the early age of thirty-six he attained the rank of Chief Constructor. The recognition of his ability was not confined to Service circles, for two years later he entered upon a most important stage in his career, by accepting the invitation of Sir William Armstrong to organize and direct the now world famous shipbuilding establishment at Elswick which was just being formed.

Here White had to contend with conditions which were largely different from those to which he was accustomed at the Admiralty, the demands of a private shipyard requiring the addition of commercial qualities to sound professional abilities. At the Admiralty he would be judged chiefly by his designing ability and by his capacity to secure that the Crown obtained the best value possible, within the limits imposed by the Board of Admiralty, in the designs he initiated or assisted in completing. At Elswick, in addition to being responsible for satisfactory designs, he would be required to make the building of ships a commercial success, and his abilities as an organizer would thereby be severely tested. That he rose to the height expected of him by Sir William Armstrong (afterwards Lord Armstrong) is evidenced by the strong reluctance of the latter to dispense with his services after he had been with the firm only two years and a half (from 1883 to 1885).

In 1885 Sir Nathaniel Barnaby was forced to relinquish his post of Director of Naval Construction at the Admiralty through continued ill-health; Lord George Hamilton was then First Lord of the Admiralty, and big changes being contemplated in the Fleet, he, with a discernment which must be placed to his credit, considered White to be the man of the moment capable of performing what can be said to have been, in the light of later events, a Herculean task. All his aspirations at the time were centred in the advancement of Elswick Shipyard, and the remuneration offered by the Admiralty was on a much less generous scale than he could expect to attain at Elswick; yet, when he found that his firm was willing, though reluctantly, to yield to the pressing inquiries of the First Lord of the Admiralty, he returned once more to the Public Service, this time as Director of Naval Construction, becoming in addition at a later period Assistant Controller of the Navy.

From this time it can be truly said his personality and abilities became of high national importance. Looking retrospectively at the sequence of events we see how first his youthful abilities attracted the notice of the chiefs of his profession at the Admiralty, how his ability and energy there placed his reputation on a surer footing, and attracted the notice of Sir William Armstrong, one of the pioneers of industry, and how he increased the range of his experience and duties at Elswick to finally give his acquirements to the nation through the Admiralty. Four years after his rejoining the Admiralty (in 1889) came the Naval Defence Act, involving an expenditure of 22½ millions sterling, and providing for the construction of seventy vessels. It is on record that Lord George Hamilton would not have consented to the spending of such

a large sum of money unless he had had the highest confidence in his Director of Naval Construction.

The years that followed were strenuous ones for both the Constructive and Engineering Departments, as many now serving at the Admiralty can remember. The strain in preparing the various designs, almost wholly new departures, was enormous, and Sir William was ever in the forefront inspiring both his superiors, colleagues, and subordinates with his unbounded faith and optimism, and by none was he more respected than by his colleagues in the engineering branch of the Admiralty. It is unnecessary in this short appreciation to recapitulate the types of ships for which he was responsible both at this and at later stages. Some strong criticisms were levelled at certain of the designs, but these were only to be expected where new departures were made, and the brilliant Director of Naval Construction was a doughty champion who was ever ready to enter the lists of controversy and offer efficient defence of his proposals. There can be no doubt that the majority of his designs called forth the eulogy of naval constructors of all countries, and in many important features were largely copied by foreign nations. In 1891 he was awarded a C.B., and in 1895 a K.C.B. and a special grant by Parliament for his exceptional services to the Navy.

Sir William's discernment was shown later on in the matter of the introduction of water-tube boilers in his Majesty's fleet, a course strongly supported by him. Much controversy followed the action of the Admiralty, and in this controversy Sir William joined and strenuously upheld the Admiralty Engineering Department.

Sir William's activities through his whole life were widely distributed, and were evidenced in many fields of mechanical science. For many years he was Instructor in Naval Architecture at South Kensington and the Royal Naval College, and most of his professional papers he contributed to the Institution of Naval Architects, of which he was Honorary Vice-President (the highest position a professional member can attain in that body). Other Societies of which he was elected President were the Institute of Marine Engineers, the Junior Institution of Engineers, the Institution of Mechanical Engineers, and the Institution of Civil Engineers. He was also President-Elect of the British Association, of which he had already been President of the Mechanical Science Section. He was a Fellow of the Royal Societies of London and Edinburgh, the recipient of many honorary degrees from various Universities, including LL.D. (Glasgow and Bristol), Sc.D. (Cambridge), D.Sc. (Durham and Columbia), D.Eng. (Sheffield).

He was an Honorary Member of many foreign scientific bodies, among which may be mentioned the Royal Academy of Science, Sweden; the Assoc. Technique Maritime; the American Societies of Civil Engineers; Mechanical Engineers, and Naval Architects, and the Canadian Society of Civil Engineers. His literary abilities greatly added to his power of conveying technical principles and knowledge to his readers and audiences. He was keen in debate, and ever ready to stenuously maintain his opinions, but always courteous to his opponents.

Sir William's strenuous application to duty rendered it necessary for him on several occasions to take prolonged absences on sick leave, and in 1902 his health became so unsatisfactory that he deemed it his duty to retire from the public service. That he did so full of honours is admitted by all.

On retirement he was given a special Parliamentary grant in recognition of his distinguished services, and in view of the fact that his health had broken down during an extended period of very severe pressure consequent on the enlarged shipbuilding programme of preceding years.

After a period of rest when he regained his health, Sir William renewed his activities in his profession by becoming associated with prominent shipbuilding and engineering firms, and, from time to time, contributed many valuable papers on Naval Architecture and kindred subjects—notably one on the principles of Submarine Design. His special interest in the inauguration of the Institute of Metals is too well known to be specially dilated upon. He was its inspiration, and was respected and beloved by all its members.

H. J. O.

SECTION II.

ABSTRACTS OF PAPERS

RELATING TO THE NON-FERROUS METALS AND THE INDUSTRIES CONNECTED THEREWITH.

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THE PROPERTIES OF METALS AND ALLOYS.

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I.—COMMON METALS.

Boronized Copper.—Particulars of the preparation and uses of this material are given by E. Weintraub, * who claims that copper, when properly deoxidized by "boron flux," can be cast as easily as brass, whilst it is said to be impossible to boronize copper or overheat the metal in melting up if it be properly treated with the boron suboxide subsequently. The cast metal has good mechanical properties and an electrical conductivity of 90–97 per cent. of that of the Mathiesson standard. The chief practical application which the metal has so far found is in the manufacture of electrical fittings.

Coating Aluminium with other Metals.—Two articles by F. Regelsberger † describe the attempts that have been made to render aluminium vessels more resistant to corrosion by coating them with a thin layer of some other metal. The patents reviewed are very numerous, but it is not clear how far success has been attained. Copper, silver, and zinc have been used for the coating, and the methods employed include electrolytic deposition, amalgamation, and wet chemical treatment.

Copper and its Oxide.—Mixtures of copper with cuprous oxide have been investigated thermally by R. E. Slade and F. D. Farrow, ‡ who find that at temperatures above 1195° the mixtures separate into two liquid layers, containing respectively 20 and 95 per cent. of cuprous oxide. The oxide itself melts at 1200°, and it is uncertain how far the mutual

* *Metal Industry*, 1912, vol. iv. p. 496.

† *Elektrochemische Zeitschrift*, 1912, vol. xix. pp. 181, 213.

‡ *Proceedings of the Royal Society*, 1912, vol. lxxxvii-A. p. 524.

miscibility increases with increase of temperature. Cuprous oxide is distinctly volatile (apart from dissociation and re-combination) at 1300° . The dissociation pressures of the system were also determined at temperatures from 1205° to 1324° .

Electro-Metallurgy of Aluminium.—An important physico-chemical study of the process of manufacture of aluminium has been made by P. P. Fedotéef and W. Iljinsky* using a laboratory furnace. The first factor studied was the composition of the electrolyte. Pure cryolite melts at 1000° . It forms a eutectic with sodium fluoride, melting at 885° . Addition of aluminium fluoride lowers the melting point, and a compound $5\text{NaF}, \text{AlF}_3$, identical with the mineral chiolite, is formed, with a transformation point of 725° . There is a second eutectic point at 685° . The change of monoclinic into regular cryolite takes place at 565° .

Fused cryolite dissolves 21 per cent. of alumina, forming a complete series of solid solutions, the freezing-point curve passing through a minimum at 935° . The eutectic of sodium fluoride and cryolite has a still greater solubility for alumina, but further addition of sodium fluoride again greatly lessens the solubility. Aluminium fluoride again lessens the solubility, but a mixture of the composition of chiolite has decided advantages, as its melting point is low and the specific gravity is also low, so diminishing the loss of metal. The quantity of alumina in the bath at 900° should then be kept at about $7\frac{1}{2}$ per cent. There is no advantage in adding alkali fluorides, and sodium chloride is harmful, as it causes loss by volatilization, as well as a formation of chlorine. Calcium fluoride, the addition of which is sometimes recommended, lowers the melting point, forming a eutectic at $815\text{--}820^{\circ}$, but its solvent power for alumina is very small, and the specific gravity is actually higher than that of aluminium.

The potential difference required is 2.1–2.2 volts, and the current efficiency on the small scale is about 70 per cent. A reaction is observed at 1.3 volt, due to the formation of carbide.

The loss of aluminium by “dissolving” in the bath has also been studied. This is largely due to the formation of carbide. Agitation of the bath is of advantage, and the use of a rotating anode, which has been proposed, may be found practicable. The quantity of aluminium which becomes emulsified in the bath may be considerable.

A sudden rise of potential is sometimes observed, and may often be checked by breaking through the solid crust and mixing in the alumina uniformly. It may also be due to too great concentration of alumina, leading to an accumulation of alumina round the anode, increasing the resistance.

Lead-Coating Process.—The Sherard Cowper-Coles process† is a rapid electrolytic method of covering steel and iron with lead. It is said to be very economical and to give a very smooth surface.

* *Zeitschrift für anorganische Chemie*, 1913, vol. lxxx. p. 113.

† *Metal Industry*, 1912, vol. iv. p. 308.

Pipes and vessels for use with corrosive liquids may be advantageously made by this process, which is also applicable for coating earthenware and wood.

Notes on Copper.—Specifications controlling the sale of various brands of copper are discussed.* The effect of impurities on the metal is considered in some detail, and a large number of photomicrographs are included.

The influence of oxygen on copper is of especial importance. For conductivity copper this impurity should be as low as possible consistent with good metal, but less than 0.4 per cent. of oxide has no effect on the other physical properties; 0.45 per cent. causes a slight loss in toughness, whilst with over 2 per cent. of oxide present there is a marked loss in ductibility even when the metal is hot.

The effect of small quantities of cuprous oxide on the microstructure is to elongate the crystal grains and to make the grain boundaries irregular in shape. On these and other effects the author bases a rapid microscopical method for estimating oxygen in copper. A series of standards was obtained, each containing a known amount of cuprous oxide, and a microscope specimen of each standard was prepared. A test ingot, cast from a melt, is polished and etched in exactly the same way as were the standards, and its oxygen content compared with the standard, using a microscope fitted with a micrometer eyepiece. The time required for such an estimation is stated to be about ten minutes.

No comment is made on the previous mechanical and heat treatment of the standards and of the test, although it is to be supposed that this is a consideration of some importance.

The influence of other common impurities† on the electrical and mechanical properties are also discussed, but it is to be regretted that the percentage of impurity present is not given for all of the photomicrographs.

Production of Metallic Coatings.—Recent advances in the spray process are described by M. A. Schoop.‡ Coatings of copper, iron, platinum, &c., as well as of easily fusible metals such as tin and lead can be made by the process.

Certain defects and difficulties in the process of spraying liquid metal have been overcome by employing as container for the molten metal a closed armoured crucible, the interior of which may be readily subjected either to pressure or to a partial vacuum. The stream of metal can thus be started or stopped at any time. The conditions of operation, degree of pressure or vacuum, design of spray nozzle, &c., vary for each metal. A characteristic feature of the metallic coatings obtained by spraying liquid metal seems to be that the metal increases in hard-

* *Metal Industry*, 1912, vol. iv. pp. 306-308, 367-368, 481-482.

† See also Johnson (*Journal of the Institute of Metals*, No. 2, 1912, vol. viii. p. 192), Greaves (*ibid.*, No. 1, 1912, vol. vii. p. 218).

‡ *Metallurgical and Chemical Engineering*, 1913, vol. xi. pp. 89-91.

ness and loses in ductility. Spraying with non-oxidizing gases such as hydrogen and nitrogen does not affect the result. Coatings may also be made by spraying metal in the form of powder or dust. The process is aided by heating the powder, gas, or surface to be coated, but this is unnecessary with certain metals provided the kinetic energy of the particles is sufficient. Very promising results have been obtained so far especially with tin and zinc, and the process is in use on a large scale in Belgium and France.

In the latest development of the spray process the metal in the form of strip or wire is fed at a uniform rate into an oxy-hydrogen or other flame (or even an arc) sufficient to readily melt it. As fast as the metal melts a stream of compressed gas directed on to it carries it away in a state of fine subdivision on to the surface to be coated. This method enables very compact apparatus of comparatively simple design to be used, and a "metal spray pistol" is shown in which the melting flame and the compressed gas are arranged concentrically in the "barrel," and the metal strip is fed up to the nozzle by a small turbine driven by the compressed gas in the "butt" of the "pistol."

Coatings of brass, copper, nickel, iron, gold, and even platinum, can be made on any surface whatever, *e.g.*, wood, paper, celluloid, lace fabric, &c.

Balloon fabric is at present being experimented with which has been coated on one side with a film of brass 0.002 millimetre thick.

Shock Tests of Copper.—The results of some shock tests of notched bars of copper are given by H. Baucke.* Frémont's method was used, with a registering method of measuring the energy absorbed. The specimens were cast in 6 centimetre cubes, forged hot, and then, if necessary, cold to 10 millimetres thickness, and then annealed. The cast copper has a very low resilience (low energy absorbed in fracture), which improves with forging, reaching a maximum when the thickness is reduced to one-fifth, and then remaining constant. The presence of even 0.06 per cent. oxygen as oxide greatly lowers the resilience. Bismuth has a bad effect, 0.025 per cent. rendering the copper brittle. 0.6 per cent. of arsenic has no bad effect, and antimony only becomes dangerous beyond 0.3 per cent.. Nickel, tin, zinc, manganese, and aluminium increase the resilience. Overheating lowers the value, even although the quantity of oxygen absorbed may be very minute. In the absence of oxide hydrogen has no effect on the metal. The best annealing temperature is 700°, and partial annealing of cold-worked copper takes place even at 200°.

Silicon in the Cast State.—Silicon was first produced commercially by the Carborundum Company.† Great advances have been made in the last few years, and castings of this element can now be obtained

* *Internationale Zeitschrift für Metallographie*, 1912, vol. iii. p. 195.

† *Metallurgical and Chemical Engineering*, 1913, vol. xi. pp. 102-103.

of all ordinary shapes and sizes. Some of the properties of this cast silicon are as follows :—

Melting point	. . . . .	1430° C.
Density	. . . . .	2·5-2·6
Coefficient of expansion (100-200° C.)	. . . . .	5·39 × 10-6
		(less than glass or platinum).
Tensile strength, approx.	. . . . .	1000 lbs. per square inch
		(exceeds that of stone ware).

The cast material is highly resistant to sulphuric and nitric acids, and is used in the form of pipes for the conveyance of acid gases from stills to condensers, and as a lining in centrifugal pumps, acid valves, &c.

Cast silicon ware is produced in practically all shapes required by chemical industry.

Corrosion of Sherardized Iron.—Experiments by F. Halla* show that wrought iron coated with zinc by the sherardizing process stands corrosion well. Experiments with sulphuric acid give little information as to the behaviour on rusting, the latter being essentially a local process, starting at a few centres and gradually spreading.

II.—*RARE METALS.*

A Possible new Platinum Metal.—From analysis of platinum minerals of the Urals, H. C. Holtz† has inferred the presence of a new metal, which forms an oxide insoluble in acids, including aqua regia, but soluble in alkalis to form a yellow solution, which remains clear on acidifying. The acid solution is decolorized by stannous chloride. The metal is soluble in nitric and hydrochloric acids, and its chloride does not yield a precipitate with ammonium chloride. It does not form an insoluble basic sulphate.

Platinum.—Facts concerning the extraction and purification of this metal are given by H. F. Keller.‡ The crude platinum or platinum ore of commerce is exclusively derived from alluvial deposits by methods of washing and concentrating similar to those used for gold. The metal so obtained contains various impurities which render it unworkable until refined.

Many attempts to render platinum malleable and ductile were made during the latter part of the eighteenth century, but it was not until the early years of the nineteenth century that the platinum industry was really founded by Englishmen.

Charles Knight in 1800 devised a process consisting in dissolving the crude metal in aqua regia, precipitating with sal ammoniac, packing the dried precipitate into conical moulds of fireclay and strongly heating. It

* *Zeitschrift für Elektrochemie*, 1913, vol. xix. p. 221.

† *Annales de Chimie et de Physique*, 1912, Series VIII. vol. xxvii. p. 559.

‡ *Metallurgical and Chemical Engineering*, 1912, vol. x. pp. 788-789.

is said that the metal was thus obtained as a coherent mass which could be hammered and worked into various forms. This process was further improved by a relative of a member of the firm of Johnson Matthey.

Robert Hare in 1847 demonstrated that the difficult and tedious process of consolidating platinum sponge could be replaced by the simple operation of melting the metal in the oxy-hydrogen flame. He melted as much as two pounds of the metal at a time.

His process was greatly improved by Deville and Debray. The furnace consists of two well-fitting pieces of quick-lime hollowed out to form a crucible or hearth. An opening at the side serves as a spout for the molten metal and for carrying off the fumes and products of combustion. The nozzle of the oxy-hydrogen blowpipe is introduced through an opening in the cover. This process was seen at work by the author at the works of Heraeus at Hanau.

The preparation of chemically pure platinum is extremely difficult and tedious, and is not described.

Vanadium.—It is found by W. Prandtl and H. Manz* that metallic vanadium is best prepared by the aluminothermic reduction of vanadium pentoxide, but that even then the product does not contain more than 96 per cent. of vanadium. The reduction of the trioxide by carbon in a vacuum electric furnace, or of the trichloride by a slight excess of sodium, does not give a pure product. The addition of calcium fluoride to the aluminothermic mixture is not essential. The specific gravity of 96 per cent. vanadium is 5.8–5.9.

III.—ALLOYS.

Alloys for Motor-Bus Construction.—Analyses of the various metals and alloys employed by the Daimler Co., Limited, of Coventry, in making motor-omnibus parts are given † along with photomicrographs of the materials. The base-chamber and gear cases are made of a copper-aluminium-zinc alloy as below—

	Per Cent.
Copper	1.9–2.2
Aluminium	86.9–89.1
Zinc	9.0–11.0

which has a tensile strength of 8–10 tons per square inch.

The radiator consists of castings of an alloy containing 86–88 per cent. of aluminium and 14–12 per cent. of copper.

The bearing brasses are made of—

	Per Cent.
Copper	76
Tin	3
Lead	1
Zinc	20

* *Zeitschrift für anorganische Chemie*, 1912, vol. lxxix. p. 209.

† *Engineering*, 1913, vol. xcv. p. 99.

A white metal alloy as below—

	Per Cent.
Copper	10
Tin	78
Antimony	12

is used for lining the bearings of crank shafts and connecting rods. Great care is taken to avoid overheating of this alloy, and pouring is always performed at the same fixed temperature, thus ensuring a uniform structure.

Alloys of Bismuth and Antimony with Selenium.—The selenides of bismuth and antimony have been examined by the thermal method by N. Parravano.* In each case the freezing-point curve shows a gap of miscibility in the liquid state, and a very sharp maximum corresponding with the compounds Bi_2Se_3 and Sb_2Se_3 respectively. There is also a compound BiSe , decomposing below its melting point, but a similar compound is not found in the antimony series. A micrographic study accompanies the curves, and confirms their indications.

Alloys of Copper, Zinc and Nickel.—A microscopical study by L. Guillet † shows that the coefficient of equivalence of nickel, when added to copper-zinc alloys is 1.2, that is, its presence diminishes the apparent proportion of zinc in that ratio. The mechanical qualities of the alloys are improved by the addition of nickel.

Alloys of Nickel, Manganese and Copper.—This ternary system, according to N. Parravano ‡ has a single liquidus surface, and the alloys should thus consist, in a state of equilibrium, of homogeneous solid solutions. The actual heterogeneous structures observed are due to imperfect diffusion.

The same author § has investigated the alloys of iron, manganese, and copper. This case is somewhat more complicated, owing to the existence of a gap in the miscibility of solid iron and copper. Hence the liquidus surface has a more complex form, and two distinct constituents are observed in micro-sections of many of the alloys.

The ternary alloys of iron, nickel, and manganese || give a single liquidus surface, and solid solutions throughout.

Alloys of Platinum and Aluminium.—M. Chouriguine ¶ gives an account of an investigation of these alloys in fuller detail than in *Comptes Rendus*, 1912, vol. clv. p. 156, an abstract of which article appeared in the *Journal*, No. II., 1912, vol. viii. p. 323.

* *Gazzetta chimica italiana*, 1913, vol. xliii. i. pp. 201, 210.

† *Comptes Rendus*, 1912, vol. clv. p. 1512.

‡ *Gazzetta chimica italiana*, 1912, vol. xlii. ii. p. 385.

§ *Ibid.*, p. 513.

|| *Ibid.*, p. 367.

¶ *Revue de Métallurgie*, 1912, vol. ix. pp. 874–883.

Alloys of Silver and Zinc.—A study of this system by H. C. H. Carpenter and W. Whiteley * shows that it is less complicated than had been supposed. The former diagram was due to Petrenko, and was in many respects contrary to the phase rule. The error in this case was probably due to the author's practice of melting the zinc, and adding solid silver, a procedure by means of which it is hardly possible to obtain homogeneous alloys.

In the present research zinc was added to molten silver, and the alloys were cast in chill moulds, 300 grammes being used for each charge. Quenching and annealing experiments were carried out on quantities of 2 grammes, heated in a vacuum in quartz vessels.

The diagram resembles that of the copper-zinc alloys. The α -range at 220° is from 0 to 25 per cent. of zinc by weight, annealing being continued for six weeks. The hardness increases with the proportion of zinc. The β -constituent is only stable above 264° , at which temperature it undergoes a eutectoid transformation into α and γ . The segregation of these two phases from "apparent β " only takes place slowly. At 48 per cent. of zinc the structure becomes homogeneous, the γ -constituent being essentially the compound Ag_2Zn_3 . The next constituent, δ , has a composition approximating to Ag_3Zn_5 , and forms solid solutions on the zinc side only. Beyond this there is an ϵ -constituent, stable only at high temperatures, and breaking up at lower temperatures into δ and η . Zinc does not retain more than 1 per cent. of silver in solid solution.

Aluminium-Zinc Alloys.—The results of an extended research into the constitution and mechanical properties of these alloys are presented in the Tenth Report to the Alloys Research Committee of the Institution of Mechanical Engineers by W. Rosenhain and S. L. Archbutt.† The work was carried out at the National Physical Laboratory. The results of the investigation of the equilibrium diagram have already been communicated (*Journal of the Institute of Metals*, No. 2, vol. vi. 1911, pp. 236–258). The report deals chiefly with the mechanical properties and microstructure, and contains 56 tables of results, 24 diagrams, and 66 photomicrographs. The materials used in making the alloys were the purest available (aluminium 99.63, zinc 99.98 per cent. purity). Sand and chill castings, and billets and slabs for rolling and drawing into bar, wire, and sheet, were prepared. The mechanical tests described are of an exhaustive nature, and include tensile tests at ordinary and elevated temperatures; compression, torsion, and hardness tests; determination of elastic modulus and elastic limit; alternating stress, single blow and alternate bending and repeated blow impact tests, and Arnold's alternate bending test. The effect of work on the cast alloys is very marked, and it has been found possible to roll into bar, and draw into wire an alloy containing as much as 25 per cent. zinc, although the alloy in the cast condition has practically no ductility. This alloy attains its maximum tensile strength (27.5 tons per square inch) in the form of $1\frac{1}{4}$ -inch hot-

* *Internationale Zeitschrift für Metallographie*, 1912, vol. iii. p. 145.

† *Proceedings of the Institution of Mechanical Engineers*, 1912, Parts I. and II., pp. 319–515.

rolled bar. Rolling down further to $\frac{3}{8}$ -inch brings about a reduction of nearly 4 tons. Results indicate that there is a limit to the amount of useful work which can be put on alloys containing more than 15 per cent. zinc. Whereas the yield points of castings are very uncertain, in the case of the wrought material they are in general definite and unmistakable. Tests under shock and alternating stress show that the alloys are not abnormally weak in this respect. Perhaps the most serious defect is great sensitiveness to rise of temperature. Thus the alloy containing 25 per cent. of zinc whose tensile strength at the ordinary temperature is 27.5 tons per square inch, at 100° C. has a tensile strength of only 18.5 tons. By addition of a small percentage of copper the tensile strength of the hot-rolled material may be raised to over 30 tons per square inch. An alloy (described in the appendix to the report) containing 25 per cent. zinc and 3 per cent. copper has in the form of $\frac{3}{8}$ -inch hot-rolled bar a maximum tensile strength of 30.9 tons per square inch with an elongation of nearly 17 per cent. Rolling temperatures need to be carefully chosen in order to obtain success with such alloys as the above. The "Specific Tenacity" is introduced in the report to denote a quantity proportional to tensile strength and inversely to specific gravity. This has been calculated by dividing maximum stress in tons per square inch by weight per cubic inch in pounds, and represents the breaking load in tons of a bar whose cross section is such as to make the weight of the bar 1 lb. per inch run. From the point of view of tensile strength alone, this figure may be regarded as representing the value of any structural material, and allows of comparisons on a correct basis between materials of widely different specific gravity. The best of the binary alloys described in the report has a specific tenacity of 231, and if we compare this with a mild steel having a tensile strength of 30 tons per square inch and a specific gravity of 7.85 which has a specific tenacity of only 105.3, it is seen that the alloy is equivalent in this respect to a steel of approximately the same specific gravity, but having a tensile strength of over 60 tons per square inch. The aluminium-zinc-copper alloy described in the appendix has a specific tenacity of 279 in the form of $\frac{3}{8}$ -inch cold-drawn bar.

Aluminium-Vanadium Alloys.—Alloys of aluminium and vanadium have been prepared by N. Czako * by the alumino-thermic process. Even with 1 per cent. of vanadium a new constituent appears, forming brilliant crystals, which fill the whole field at 3.45 per cent., and appear to be a compound Al_3V . This compound is hard, and may be isolated chemically. The chemical and microscopical tests also appear to indicate two other compounds, AlV and AlV_2 .

Carbides of Manganese and Nickel.—Manganese carbide, according to O. Ruff and E. Gersten, † is prepared by saturating manganese with carbon at 1600° under 20 mm. pressure. After crushing, it is

* *Comptes Rendus*, 1913, vol. clvi. p. 140.

† *Berichte der deutschen chemischen Gesellschaft*, 1913, vol. xlv. p. 400.

separated from graphite by washing with acetylene tetrabromide, and then has the exact composition, Mn_3C . It is very soft (H between 1 and 2), and has the density 6.89. Its heat of formation is +12.9 Cal.

Nickel carbide, Ni_3C , has not been isolated in a pure condition, as it readily decomposes during cooling, and the great toughness of the quenched alloys makes it impossible to separate the carbide by washing. Its molecular heat of formation is about -390 calories.

Chemical Method for the Study of Alloys.—The value of chemical methods, as applied to the isolation of compounds, in the study of the constitution of alloys is discussed by A. Portevin.* The sources of error usually recognized are included under the following heads:—

1. The crystals isolated by chemical means may have a composition which depends on the reagent employed, *e.g.*, acid of varying concentration.

2. A residue may be obtained of a definite composition from a mixture of solid solutions.

3. In contact with reagents compounds may be formed which are not the same as the compounds present in the alloys.

In addition to these there are two other sources of error due to want of homogeneity of the crystals isolated. These which are discussed at greater length are caused by—

- (a) The inclusion of liquid in primary crystals. Primary crystals of more or less regular outward form may during growth enclose more or less completely some of the liquid alloy. Such enclosures are not or only partially dissolved by the reagent which dissolves the matrix. This practically is a general rule in many cases, such as compounds of copper with aluminium, tin, and antimony, and also certain carbides of iron.

- (b) The envelopment of existing crystals by a definite compound formed by reaction between these crystals and the surrounding matrix. In this case thermal analysis also is unreliable, and micrographic examination is necessary in order to show the heterogeneous character of the crystals. The author emphasizes the importance of micrographic work, which in many cases is the only method of avoiding serious error, at the same time being quicker than other, such as chemical, methods.

Copper-Zinc Alloys.—The tensile strength of the alloys of copper and zinc has been studied by J. M. Lohr.† The alloys were melted in a granular carbon electric resistance furnace, using graphite crucibles, and were cast in graphite moulds, the latter being heated to redness before pouring. In order to avoid the carrying of particles of oxide into the metal, the crucibles were poured from the bottom by means of a hole closed by a graphite plug. The bars were removed from the mould while hot, and quenched in water. Each bar was analysed.

The α -brasses in the quenched condition have an almost constant tensile strength, and the appearance of the β -phase coincides with an

* *Revue de Métallurgie*, 1912, vol. ix. p. 884.

† *Journal of Physical Chemistry*, 1913, vol. xvii. p. 1.

increase of strength. The maximum is found in the β -region, at 45 per cent. of zinc, and is then about 31.7 tons per square inch. As the percentage of zinc in the β -alloys increases, the strength falls off rapidly, and becomes very low with the appearance of the γ -phase. The elongation reaches a maximum at 35 per cent. of zinc, and then falls off, reaching zero at 52.5 per cent. of zinc.

The best pouring temperature is between 100° and 200° above the liquidus. A higher temperature always gives an oxidized casting.

The quenched alloys are always porous. Slow cooling gives sound alloys, but the structure is coarser and the strength less. It appears that quenching forms a thin shell of hard metal on the outside, through which the gases cannot escape.

Copper-Zinc, Silver-Zinc, and Silver-Cadmium Equilibria.—

H. C. H. Carpenter* has called attention to the remarkable resemblance between the alloys formed by these three pairs of metals. The most important alloys in each case are those containing the α - and β -phases, and in each series the character of these phases is determined by the γ -constituent, which has the formula Cu_3Zn_3 , Ag_2Zn_3 , and Ag_2Cd_3 in the three cases considered. The β -phase is only stable above a certain limiting temperature, below which it is resolved into α and γ , the form of the solubility curves and of the eutectoid horizontal being essentially the same in all three series. The β -areas are grouped about compositions corresponding approximately with CuZn , AgZn , and AgCd respectively, but there is no proof of the actual existence of such compounds. The resemblance is very close, the β -constituents in the CuZn and AgZn series having the same colour, whilst all three γ constituents are highly brittle.

The copper-cadmium series is different in character, but Guertler has suggested that the gold-mercury series may show an analogy.

Effect of Heating Brass in Hydrogen.—As a result of heating brass in pure dry hydrogen E. A. Lewis† has found that with a very pure brass most of the zinc is lost by volatilization, but complete separation could not be effected. The temperature attained was about 750° C., and the heats lasted from one to twelve hours.

It was found that any tin present remained with the copper, but the extraction of lead by volatilization was complete. The brass did not show any tendency to become brittle as the result of annealing in hydrogen, whereas it is well known that copper is soon rendered very brittle by such treatment. It is concluded that chemically combined oxygen is not an essential constituent of alloys of copper and zinc. T. Turner,‡ on the other hand, supposes that oxygen in brass is present as oxide of zinc mechanically entangled in the alloy, and quotes the pitting observed in brass when examined under the microscope as evidence supporting this hypothesis.

* *Internationale Zeitschrift für Metallographie*, 1912, vol. iii. p. 170.

† *Proceedings of Chemical Society*, 1912, vol. xxviii. p. 290.

‡ *Journal of the Institute of Metals*, 1912, No. 2, vol. viii. p. 249.

Etching at High Temperatures.—The method of etching alloys at high temperatures is criticized by H. Hanemann.* In an ordinary section etched cold the crystals are cut through by the plane of the section. When a solid solution undergoes change any segregate which forms appears first at the bounding surface of the crystal grain, and this is revealed by the ordinary method of etching. On the other hand, when a specimen is etched at a high temperature, the surface is necessarily a bounding surface of the crystals, and not a section through them. Any transformation occurring after the preparation of the specimen and before etching is thus not revealed if the segregate forms at the boundaries. Further, as structural changes are very rapid at high temperatures, the structure may alter very appreciably during the etching process.

Molecular Weights of Solid and Liquid Metals.—Cryoscopic measurements by M. Padoa and F. Bovini† show that silicon is monatomic in both liquid and solid copper. It is also found that the molecular complexity of cadmium is the same in both liquid and solid tin.

Monel Metal.—The physical properties and chemical composition of this alloy are discussed.‡

It is largely used in the United States for battleship propellers, whilst in Germany it has been adopted for locomotive fireboxes, since its strength is but little impaired by high temperatures (1000° F.).

Pump rods and ore dressing screens are also often made of monel metal.

The U.S. Government have specified the following composition for monel metal for propeller manufacture:—

	Per Cent.
Nickel	60
Copper	33
Iron	6.5
Aluminium	0.5
Lead	nil

The physical and mechanical properties of monel metal of above composition are given below:—

	Cast.	Rolled.
Tenacity	82,500 lbs. per square inch.	86,900 lbs. per square inch.
Elastic limit	37,500 lbs. per square inch.	58,870 lbs. per square inch.
Elongation	44 per cent.	40 per cent.
Melting point	1360° C.	...
Specific gravity	8.87	...
Electrical conductivity	4 (Cu=100).	...
Shrinkage	$\frac{1}{4}$ inch per foot.	...
Hardness (Shore)	22	27

* *Internationale Zeitschrift für Metallographie*, 1912, vol. iii. p. 176.

† *Atti della R. Accademia dei Lincei*, 1912, Series V., vol. xxi. ii. p. 708.

‡ *Engineering*, 1912, vol. xciv. p. 690.

Monel metal is prepared by direct reduction from nickel-copper matte, and the metal prepared by alloying the constituent metals together is said not to possess the same physical properties as monel metal proper. Experiments on the corrodibility of monel metal indicate that it is at least comparable with the best manganese bronze in this respect.

It is said that in casting this alloy an addition of 2 oz. magnesium per 100 lbs. remedies difficulties due to oxide and dissolved gases.

New Alloys.—An alloy of silver and aluminium under the name of "Argental" is said* to possess good casting properties and a fine white colour; it rolls and machines well and takes a fine polish. It is suggested that it could be employed in making fittings for instruments, table silver, and ornamental hardware.

A new copper alloy, said† to offer great resistance to chemical corrosion has been made by alloying 80–95 per cent. of copper with 20–5 per cent. of a cobalt tin alloy (containing 40 per cent. cobalt and 60 per cent. tin).

Spongy Metals.—An article by F. Laur‡ describes the method recently introduced of obtaining spongy metals, such as spongy lead for accumulators, by centrifuging an alloy, say of lead and antimony, before complete solidification, so expelling the eutectic. The metal is supported in the centrifugal machine by a suitable wire netting.

Undercooled Solid Solutions.—A paper by H. Hanemann,§ dealing more especially with austenite and martensite in steels, contains important conclusions as to the nature of the solid phases in undercooled solid solutions in metallic alloys in general. A eutectoid, the formation of which has been suppressed by undercooling, is not necessarily formed when the alloy is tempered. The prolongation of solubility curves into the metastable region may cause an overlapping of homogeneous and heterogeneous regions. In such a case several different crystallizations may occur, and it depends on the relative rate of formation of the different solid phases which of them will make its appearance. Some phases may only exist in the metastable region, and although this case may be exceptional, it is clear that it is not legitimate to infer the structure of undercooled alloys from a knowledge of the stable system alone.

Quaternary Alloys of Iron, Nickel, Manganese, and Copper.—This quaternary system has been investigated by N. Parravano,|| and a number of ternary sections of the tetrahedral model have been constructed. The system is of the type that might be expected from a consideration of the component ternary systems. Photomicrographs of alloys composed of two solid solutions are given.

* *Metal Industry*, 1912, vol. iv. p. 368.

† *Ibid.*, 1913, vol. v. p. 11.

‡ *Métaux et Alliages*, 1913, vol. vi. p. 1.

§ *Internationale Zeitschrift für Metallographie*, 1912, vol. iii. p. 127.

|| *Gazzetta chimica italiana*, 1912, vol. xlii. ii. p. 589.

IV.—PHYSICAL PROPERTIES.

Annealing of Cold-Worked Metals and Alloys.—The effect of annealing on the tensile strength of hard-drawn wires of nickel, mild and high carbon steels, 67-33 brass and 60-40 brass has been studied by L. Guillet,* the elastic limit (for nickel and steel), maximum stress, and percentage elongation being given in a large number of tests. The results of these tests show that in all cases the temperature of complete annealing, as indicated by a rapid fall in maximum strength and elastic limit and a rapid increase in percentage elongation, is practically independent of the amount of cold work. These temperatures are 700° to 750° C. for nickel, 750° to 800° C. for mild steel, 700° to 750° C. for high carbon steel, and 350° to 400° C. for brass.

Brown Gold.—The properties of brown gold have been further studied by M. Hanriot and F. Raoult.† Brown gold is fairly rapidly attacked by nitric acid, the presence of nitrous acid diminishing the action. Chloroauric acid dissolves it when warmed, and the dark solutions deposit crystalline gold on cooling.

Crystallized gold, as far as measurements of the magnetic susceptibility indicate, consists largely of the β -variety. Chloroauric acid serves to separate the two modifications.

Changes in Electrical Resistance of a Metal on Melting.—The results of an investigation of the electrical resistance of metals, both when solid and liquid, are given by E. F. Northrup and V. A. Suydam,‡ in a preliminary paper which does not contain any description of the methods employed. It would appear, however, that the resistivity was estimated by the potentiometer method, using a Kelvin double bridge, the temperature being measured simultaneously by a thermocouple. The metals tested up to the present include lead, cadmium, zinc, tin, bismuth, and antimony, with mercury as a standard. The tests were taken from 0° C. to 750° C. (or to the boiling point of the metal if below this), and, in the case of antimony, up to 950° C. In general the characteristic results comprise a gradual increase in resistance up to the melting point, when the increase becomes much more rapid, slowing down again very abruptly when all the metal is in the liquid state. Bismuth is exceptional, the resistance showing a sudden decrease during the solid-liquid change. Molten zinc is shown to have a negative temperature coefficient.

Cold Working.—A series of tests of cold-rolled plates, by M. Hanriot,§ indicate that when the amount of cold work is small, great differences in hardness may occur with very slight differences in breaking

* *Revue de Métallurgie*, 1913, vol. x. pp. 665-676.

† *Comptes Rendus*, 1912, vol. clv. p. 1085.

‡ *Journal of the Franklin Institute*, 1913, vol. clxxv. p. 153.

§ *Comptes Rendus*, 1913, vol. clv. p. 971.

strength and elongation, but the latter properties change suddenly when the cold work exceeds a certain value.

The progress made within recent years in our knowledge of the mechanical hardening or cold working of metals (*l'ecrouissage*) is reviewed by P. Galy-Aché,* and present views on the subject are discussed. Mechanical hardening does not take place until the elastic limit has been exceeded and the metal has suffered permanent deformation. A characteristic effect of mechanical hardening is the raising of the elastic limit, and the elastic limit acquired by a metal when deformed by cold working is equal to the force producing the deformation. This is given as the fundamental law of mechanical hardening. The hardness decreases when the temperature rises and when the temperature of annealing is increased; it tends to reach a minimum at a temperature which may be called the temperature of complete annealing of the metal.

The hypothesis of the existence of an amorphous modification of metals and the work of Ewing and Rosenhain on the plastic deformation of metals are referred to. In the fully annealed condition, what is called a mechanically perfect metal consists of an aggregate of crystals imbedded in a very strong and flexible amorphous cement. The elastic deformations of such a metal are referred to the amorphous cement which surrounds the crystals, while the permanent deformations are due (following Ewing and Rosenhain) to slip along cleavage planes of the crystals themselves.

Hirn's experiment of subjecting a known mass of a metal to the blow of a steel hammer and measuring the quantity of heat produced leads to a theoretical definition of mechanical hardening. That part of the work due to the fall of the hammer—or work otherwise done on the metal—which is not recovered in the form of heat is a measure of the mechanical hardening of the metal caused by such work. In the case of lead—a plastic metal incapable of being mechanically hardened—all the work which it receives is recovered in the form of heat, while in the case of copper and other metals which are mechanically hardened a portion only of this work is recoverable in the form of heat, the other part being used in modifying the properties of the metal which has suffered deformation. Mechanical hardening is thus a form of work, and such work is proportional to the square of the acquired limit of elasticity of the metal.

The author also refers to the singularities in the behaviour of iron and steel, and discusses the close relation between hardening by tempering and mechanical hardening.

Colloidal Gold.—An historical account of colloidal gold is given by A. Connejo.†

Conductivity and the Dispersoid Theory.—An application of colloidal chemistry to metallography has been made by P. P. von Weimarn,‡ who examines the electrical conductivity of alloys from the

* *Revue de Métallurgie*, 1913, vol. x. pp. 585-594.

† *Kolloid-Zeitschrift*, 1913, vol. xii. p. 1.

‡ *Internationale Zeitschrift für Metallographie*, 1912, vol. iii. p. 65.

point of view of disperse systems. The degree of dispersion of a system is defined by the ratio $\frac{w}{v}$, where w is the surface area of that phase

which is dispersed through the other, and v is its volume. The energy-content of a phase increases with its degree of dispersion, and the physical properties are correspondingly altered.

With increase of the internal surface the electrical conductivity, and also its temperature coefficient, must diminish, so that even in a pure metal the conductivity should be less, the finer the grain. This result is claimed to be in accordance with experience. The illustration quoted, that of thin films, is not conclusive, as into this case much more complex factors are known to enter.

The same conditions are considered to prevail in alloys, and the high resistance and low temperature-coefficient of solid solutions are attributed to their high degree of dispersion. In this form the theory is similar to that of Liebenow, to which weighty objections have been advanced on several grounds.

Conductivity of Alloys.—A. P. Schleicher* has made experiments to determine the influence of the mechanical arrangement of the constituents in a conglomerate on the electrical conductivity. In one series amalgamated copper wires were threaded through a glass tube and the spaces between them filled with mercury. In such a composite mass the *conductivity* is a linear function of the composition by volume. In the second series short lengths of amalgamated copper wire were placed in a tube and this was filled up with mercury. In this case the *resistance* of the mass is a linear function of the composition by volume. The latter condition approaches more nearly to the state of things occurring in alloys which consist of conglomerates.

Crystallization of Bismuth and Antimony.—The connection between crystal size and rapidity of cooling has been investigated by E. Bekier† in the cases of bismuth and antimony, by pouring the molten metal into a bath of liquid paraffin or into an iron mould, the temperatures used lying between -70° and 600° . Generally, the number of crystallites per unit area increases with the degree of under-cooling, but antimony shows an increase of crystal size at low temperatures owing to diminishing crystallizing power. It is suggested that at a sufficiently low temperature the power of forming crystal centres might vanish in the case of antimony, giving rise to the known amorphous modification. The size of the crystallites depends on two factors, the facility with which crystal centres are formed, and the linear velocity of crystallization.

Disintegration of Heated Platinum.—J. H. T. Roberts‡ has studied the cause of the volatilization of platinum and other similar

* *Zeitschrift für Elektrochemie*, 1912, vol. xviii. p. 998.

† *Zeitschrift für anorganische Chemie*, 1912, vol. lxxviii. p. 178.

‡ *Philosophical Magazine*, 1913, Series VI., vol. xxv. p. 270.

metals. This has often been attributed to oxidation, but Brookes regards it as being due to true sublimation. In the present research the vapour condensation method of detecting minute nuclei has been employed. It is found that platinum gives off recognizable nuclei as low as 500° , but the loss only becomes weighable above 1000° . The loss only occurs in oxygen, not in a vacuum or in an indifferent gas, and the rate of loss of weight is roughly proportional to the oxygen pressure, pointing to the formation of an endothermic oxide. The other platinum metals behave similarly, but palladium undergoes true volatilization in a vacuum without forming nuclei.

Effect of Temperature on Internal Friction of Metals.—

Further results of oscillatory torsion tests on wires of various metals are published by C. E. Guye.* In this series of tests higher temperatures were employed than in the earlier work, and results have been obtained from which the author deduces some important facts concerning the elastic straining of metals and solids generally. The metals experimented with include copper, silver, gold, aluminium, iron, steel, zinc, and magnesium.

Wires of these metals were annealed for some time to secure homogeneity of structure, and then tested in a form of torsion dynamometer working in vacuo. Only small deflections (2° – 3°) were used, thus avoiding any possibility of exceeding the elastic limit. Tests were made on both rising and falling temperatures and no appreciable thermal hysteresis was noted. It was found that, whilst alteration of the load on the free end of the wire caused considerable variations in the damping of the oscillations, particularly at the higher temperatures (150° – 400° C.), nevertheless the velocity of the oscillation does not affect its logarithmic decrement, neither does change in temperature produce any measurable effect in the time of vibration.

The internal friction was measured in each case by the value of the logarithmic decrement of the angle of swing at various temperatures, and by plotting the decrement as a function of temperature.

For observations above atmospheric temperature the wire was heated in a small electric furnace, and for low temperature work another form of apparatus was devised, capable of immersion in the cold bath. This was fitted with photographic apparatus for recording the oscillations.

As a result of a number of experiments, it was found that the internal friction increases with rise in temperature, and decreases for the lower temperatures, and it is therefore suggested that at absolute zero bodies should be perfectly elastic.

In discussing the results of the experiments the internal friction is compared with magnetic induction, both of which function similarly with respect to temperature. Also, since magnetism was found to have a very definite effect on the oscillations of an iron wire, the question of internal friction is considered to be partly dependent on molecular orientation.

In this connection an experiment is described in which, by using two

* *Journal de Physique*, 1912, vol. ii. p. 620.

frames, one oscillating and one stationary, each containing a large number of small compass needles, it is shown that the mere fact of the oscillation will cause a rearrangement of the needles at the end of every swing. Imagining the compass needles to be molecules the author draws some interesting conclusions regarding the dissipation of energy during the elastic straining of metals.

Deductions are also drawn from the kinetic theory of gases from which it is concluded that the molecular heat energy of a metal is largely responsible for its internal friction.

The paper is illustrated by a number of diagrams and curves.

Electrical Conductivity of Copper-Arsenic Alloys.—Alloys containing up to 45 per cent. of arsenic have been studied by N. Puschin and E. Dischler.* The resistance of copper is greatly increased by alloying with arsenic up to 6 per cent., this marking the limit of the solid solution, and another break in the curve is found at 32 per cent. of arsenic, corresponding with the compound Cu_3As . From this point onwards the resistance diminishes slightly, without indicating whether a compound Cu_3As_2 is formed or not. Solid solutions do not exist in this part of the series. The alloys rich in arsenic change their conductivity considerably on annealing, indicating the occurrence of reactions in the solid state.

Electrical Resistance of Stretched and Twisted Wires.—Extensive experiments by F. Credner† show that the resistance of a freshly stretched gold, silver, or copper wire falls at constant temperature, the more rapidly the higher the temperature. By successive warming, the resistance being measured cold, it is found that a minimum resistance is obtained at a definite temperature, which is independent of the size of the wire. This temperature is 480° for gold and silver, and 450° for copper, and is that at which coarse crystallization sets in. At higher temperatures cavities appear in the metal, and the resistance increases. The resistance of nickel falls to a minimum by heating to 550° , and then remains constant for 300° . The minimum for iron is at 600° .

The stretching produces slipping over cleavage planes, producing an oriented structure, which disappears on warming. Torsion on bending produces cavities, and the increased resistance due to these does not disappear on heating.

With falling temperature the resistance of a stretched wire falls more slowly in a direction parallel with its length than in a transverse direction. The increased resistance of a stretched wire is due essentially to the orientation of lamellæ. There is no evidence for the formation of an amorphous phase.

Electrolytic Potential of Tantalum.—Measurements of the electrolytic potential of tantalum have been made by G. von Hevesey

* *Zeitschrift für anorganische Chemie*, 1913, vol. lxxx. p. 65.

† *Zeitschrift für physikalische Chemie*, 1913, vol. lxxxii. p. 457.

and R. E. Slade,* using a dilute solution of tantalum pentafluoride as the electrolyte. It is found that active tantalum has a potential near to that of copper, whilst passive tantalum has a potential about 1 volt different from that of silver, being nobler than the latter.

Electrolytic Silver.—"Black silver," prepared by the reduction of silver salts, has been studied by V. Kohlschütter and T. Toropoff.† This material does not exhibit any obvious crystalline characters, but rapidly passes into the crystalline modification. It is a transitional form between the true colloidal silver and the crystalline metal. When silver is deposited electrolytically, using high current density and dilute electrolyte, the initial deposit is greyish-white, but almost immediately a black or dark brown mossy deposit is formed, which collects as a black slime, but is seen to be crystalline under the microscope. The black material is best obtained from an acid solution of the nitrate. If the process be watched under the microscope a brown colloidal stream is seen to form, out of which the minute crystals are deposited. Transformation into stable larger crystals, accompanied by contraction, takes place readily, propagating itself in an acid solution with almost explosive rapidity. The potential difference at the terminals is a maximum at the moment at which the black deposit gives place to white. It is during the period of rapid exhaustion of the electrolyte in the neighbourhood of the small cathode that the black silver is formed. An increase in viscosity favours the black form.

The forms of silver precipitated by metals have been studied by V. Kohlschütter, T. Toropoff, and W. Pfander.‡ The form which the silver takes is determined by the velocity of reaction, and this is again influenced by the nature of the metal used, the nature and concentration of the electrolyte, and the presence of foreign substances. Thus zinc, which acts rapidly, produces a blacker and less crystalline metal than copper.

The effect of foreign substances has been studied in more detail by V. Kohlschütter and H. Schacht.§ The appearance of the deposit is influenced in a characteristic manner by the addition of many salts, such as the nitrates of copper, zinc, lead, &c. The influence is dependent on the formation of colloidal hydroxides, which are adsorbed, and influence the distribution of the nuclei.

V. Kohlschütter|| has also investigated the electrolysis of complex silver salts, and finds that compounds of the "subhaloid" type are formed as intermediate products. A thin colloidal layer is formed on the cathode, above which the silver is deposited.

Foam-Structure of Metals.—In two articles, G. Quincke¶ has summarized his work since 1858, which bears on his hypothesis of the foam-structure of metals, an hypothesis which is now under investiga-

* *Zeitschrift für Elektrochemie*, 1912, vol. xviii. p. 1001.

† *Ibid.*, 1913, vol. xix. p. 161.

‡ *Ibid.*, p. 172.

§ *Ibid.*, p. 172.

¶ *Internationale Zeitschrift für Metallographie*, 1912, vol. iii. p. 23.

tion by a committee of this Institute. The author's researches in this direction are very extensive, and the range of subjects dealt with from this point of view is wide, including the formation of crystals, the effect of cold-working and annealing, the velocity of crystallization, the structure of electro-deposited metals and of thin films, the nature of allotropy, electrical conductivity, and the hardening of steel.

Hall Effect in Antimony.—The Hall effect in antimony, according to J. Becquerel, L. Matout, and W. Wright,* is positive, and is greatest at low temperatures. It depends on the orientation. The curves showing the variation of the E.M.F. with the magnetic field consist of two intersecting straight lines.

Hardening without Deformation.—A further paper by M. Harriot† shows that when a silver cylinder, 15 millimetres high and 50 millimetres in diameter, is placed in a cavity which it exactly fits, in a steel block, and is set between two tightly fitting pistons, it may be compressed 0.65 per cent. by hammering, but the increase in hardness is as much as from 23.5 to 39.5, or in the ratio 1:1.68. The hardness is increased equally throughout, as is found on cutting through the specimen. The elongation and breaking load are altered in nearly the same proportion. Zinc gives similar, but less uniform, results.

Lastly, cubes of metal were compressed uniformly by enclosing vaseline and applying a pressure of 10,000 kilogrammes per square centimetre. The following results have been obtained:—

Metal.	Hardness before Compression.	Hardness after Compression.	Hardening Ratio.
Silver	19.4	36.0	1.8
Copper	27.0	46.1	1.7
Aluminium	14.6	19.0	1.3
Iron	57.7	62.3	1.1
Zinc	33.1	43.0	1.33
Brass	24.0	36.5	1.5

Heusler Alloys.—Three papers dealing with the magnetic properties of these alloys were presented at a general discussion. F. Heusler and E. Take‡ discuss in detail the hypothesis put forward by them in 1909, that the magnetism of the Heusler alloys is to be explained by the occurrence in them of ternary compounds of Cu, Al, and Mn, having the general formula $Al_x(Mn, Cu_{3x})_{3x}$. Assuming this hypothesis to be true, an attempt is made to explain some of the effects observed on subjecting the alloys to annealing and quenching.

Magnetometric, thermometric, and metallographic evidence is given by

* *Comptes Rendus*, 1913, vol. clvi. p. 463.

† *Ibid.*, 1912, vol. clv. p. 1502.

‡ *Transactions of the Faraday Society*, 1912, vol. viii. pp. 169–184.

A. D. Ross* in support of his theory that the magnetic Heusler alloys consist of solid solutions of the binary compounds Cu_3Al and Mn_3Al , and that the magnetic properties depend on the presence of these solid solutions. The variation of magnetic properties of the alloys with constitution and thermal treatment is studied, and the general magnetic properties of alloys of copper and manganese with tin, antimony, and bismuth, of copper-manganese, copper-aluminium, manganese-antimony, and manganese-boron alloys are dealt with.

A. A. Knowlton and D. C. Clifford† discuss the Heusler alloys with regard to the best methods of preparation and heat treatment for obtaining high magnetic permeability, their tests point to the alloys being of the nature of solid solutions.

In the subsequent discussion W. Rosenhain gave some details of the work done at the National Physical Laboratory on the Cu-Al-Mn and Al-Mn alloys. His observations were confined to a range of 11 per cent. aluminium and 10 per cent. manganese. In that range there was no evidence of the existence of a ternary compound. Quite apart from copper the alloys of aluminium and manganese were strongly magnetic, particularly near the manganese end of the series, where a definite compound of the two metals appeared to exist. His view was that the Heusler alloys owed their magnetic properties to the presence in them of this aluminium-manganese compound.

Hysteresis of Magnetic Substances.—A paper by G. Vallauri‡ discusses Weiss's theory of ferromagnetism, and applies it to the case of the hysteresis of iron.

Latent Heat of Evaporation of Metals.—Measurements by A. Wehnelt and C. Musceleanu,§ using a method in which the metal studied became the anode in a tube with a Wehnelt cathode and the radiated energy was measured, give the following results for the latent heat of evaporation of some metals:

	Per Cent.
Mercury	63·6
Cadmium	181·0
Zinc	365·8
Magnesium	1700·0
Bismuth	161·5

The only metal for which the latent heat has been measured directly previously is mercury. The result is in good agreement, and the method may be applied to any other metals.

Calculations by E. van Aubel|| show that Trouton's law is fulfilled for mercury, cadmium, zinc, and bismuth, previous experimental results being employed for the purpose.

* *Transactions of the Faraday Society*, 1912, vol. viii. pp. 185-194.

† *Ibid.*, pp. 195-206.

‡ *Physikalische Zeitschrift*, 1913, vol. xiv. p. 118.

§ *Berichte der deutschen physikalischen Gesellschaft*, 1912, vol. xiv. p. 1032.

|| *Comptes Rendus*, 1913, vol. clvi. p. 456.

Long-focus Microscope—Study of Oxidation and Other Phenomena shown by Metals under the Influence of Heat.—By interposing a double concave lens (in the tube of the microscope) just outside the focus of the objective, F. Robin* has devised a microscope which permits of a greater distance between the object to be examined and the objective, whilst still giving reasonably high magnifications. With the surface of the specimen as much as 5 centimetres from the objective, magnifications of 200 diameters were obtained.

The instrument has enabled the phenomena occurring on heating polished surfaces of specimens of various metals and alloys to be observed. The rate of oxidation of the constituents of steel and other alloys at various temperatures has been studied. Whereas at lower temperatures oxidation is characterized by the formation of more or less uniform coloured pellicles, at higher temperatures the action becomes local and "corrosive." The crystal boundaries of solid solutions and pure metals are developed quite sharply at certain more or less definite temperatures, and at higher temperatures the large grains may frequently be observed to split up into smaller ones. The paper is illustrated with diagrams and photomicrographs.

Mechanical Hardening.—The subject of mechanical hardening of metals is dealt with by M. Hanriot,† who proposes to give numerical expression to this property based on the results of hardness determinations. The author points out that the definitions of mechanical hardening usually given are very vague, the most precise being that of Charbonnier and Galy-Aché, viz. "the property of elevation of elastic limit which is given to metals by mechanical treatment." It is universally held that mechanical hardening is the result of deformation of the metal, but the only proposed figure is that due to Grard, who gives the following expression for rolling:—

$$E = \frac{S-s}{S} \times 100$$

where S and s are the sections before and after rolling. The author proposes as a definition of mechanical hardening the following:—A metal is mechanically (or work-) hardened, which by a suitable annealing undergoes a modification of its physical (or mechanical) properties—apart altogether from chemical transformations. Of the mechanical properties that of hardness is the most sensitive and the easiest to measure.

Determination of Hardness.—The author employs a modified Brinell test, using a small ball of 3 millimetres diameter and a load of 30 kilogrammes. The apparatus is in the form of a balance, the ball being carried on the underside of the balance pan, and the specimen suitably supported beneath. The hardness thus obtained is generally considerably smaller than that given when a 10-millimetre ball is used with a load of 1000 kilogrammes. The difference is probably due, as suggested by Meyer, to the hardening caused by the indentation of the metal by the ball.

* *Bulletin de la Société d'Encouragement*, 1912, vol. cxviii, pp. 204-231.

† *Revue de Métallurgie*, 1913, vol. x, pp. 595-607.

Lead, which is not capable of being mechanically hardened, gives the same results irrespective of the load and the size of the ball. In the case of metals and alloys, which can be hardened by mechanical means, the following experiments were carried out in order to eliminate as far possible the inaccuracy due to the hardening which results from forcing the ball into the metal. The test was carried out in the ordinary way, and the diameter of the impression measured, the material tested being a sample of aluminium bronze in the annealed condition. The alloy was then annealed again and the ball forced again into the same spot, the increased diameter of the impression being measured. These operations were repeated until the diameter of the impression showed no further increase. With the load of 1000 kilogrammes the hardness number, D , was decreased gradually from 94 to 35, at which figure it remained constant. With a load of 30 kilogrammes, the hardness number, d , decreased similarly from 61 to 24. The hardness numbers obtained with large ball and large load were never the same as with a small ball and small load, but the ratio $\frac{D}{d}$ was practically constant at 1.45 throughout the two series of tests. Similar tests were carried out, using other metals and alloys, and the following figures for the ratio $\frac{D}{d}$ were found:—

Aluminium bronze (8 per cent. Al), 1.45; nickel, 1.33; silver coinage alloy (835 fine), 1.19; gold (999 fine), 1.02; lead, 1.0. It is concluded from these experiments that the actual hardness numbers given by the Brinell test are generally too high, *e.g.* in the case of aluminium bronze it is less than 24, although the number usually obtained is 94.

Hardness Tests as a Measure of Mechanical Hardening.—Although there is no method for measuring the hardness independent of the instrument used, it was found that for the same metal the figures given by different apparatus are in constant proportion. The author, therefore, proposes to express mechanical hardening by the ratio of the hardness numbers of the metal as tested and of the same metal completely annealed. This ratio is independent of the apparatus. In order to compare the hardness and cold-work numbers with the other mechanical properties plates of silver were cut from the same ingot, reheated together, and then rolled, each plate a different number of times. Hardness and tensile tests were then made. The following table gives the results obtained:—

	Hardness.	Cold-Work Number.	Maximum Stress, Kilogrammes per Sq. Millimetre.	Elongation. Per Cent.
Annealed metal	25	1	8.5	31
Rolled "	28	1.12	8.8	30
" "	38	1.58	9.5	27
" "	45	1.80	14.4	12
" "	51	2.04	15.0	4
" "	66	2.44	22.0	6

From this it is concluded that of the three constants studied, the hardness figures are the only ones which detect a small amount of mechanical work.

Mechanical Hardening by Compression.—It is generally held that there is a close connection between mechanical hardening and deformation, but the author has observed that in striking medals in a coinage press the deformation is produced almost entirely by the first blow, although it is this which hardens the metal least. Experiments were then made to harden metals without deformation. Cubes of silver, copper, iron, brass, aluminium, and zinc were immersed in vaseline in steel cylinders and subjected to compression of about 65 tons per square inch by means of hydraulic pressure. In all cases pronounced hardening was found to have taken place without any apparent deformation, and in the case of brass, which was examined microscopically, no internal crystalline deformation was observed.

Mechanical Hardening by Means of Tensile Stress.—A number of plates were cut from the same ingot of steel, annealed together, and then cold rolled to different extents. Test-pieces of the same section were then cut from the rolled plates and tested in tension, the hardness numbers being obtained before and after test. The following table gives the results obtained:—

No.	Initial Hardness.	Maximum Stress.	Elongation per Cent.	Hardness after Test.	Increase in Hardness.
1	25	8.5	31	40	+15
2	28	8.8	30	36	+8
3	29	9.5	27	39	+10
4	38	10.5	12	38	0
5	51	15.0	4	49	-2
6	65	22.0	6	62	-3
7	68	30.0	4	57	-11

Similar results with brass and aluminium, showing that metals which have been greatly hardened by severe cold rolling are actually softened after being subjected to tensile tests.

It is also shown that when annealed metals and alloys (aluminium, silver, brass, aluminium bronze) are tested in tension the hardness remains unchanged until a permanent extension takes place. Tests, however, on cold rolled brass (66 per cent. copper) indicate that when metals and alloys have been severely worked, the hardness decreases before any permanent extension takes place.

Melting Points of Metals.—A list is given * containing the most recent values for the melting points of 75 of the chemical elements. Most of the values have been reduced to the thermodynamic scale.

Amongst the commoner metals included in this list are—

* *Journal of the Franklin Institute*, 1912, vol. clxxiv, p. 227.

	Degrees F.	Degrees C.
Mercury	- 37·7	- 38·7
Tin	449·4	231·9
Cadmium	609·6	320·9
Lead	621·1	327·4
Zinc	786·9	419·4
Antimony	1166·0	630·0
Aluminium	1217·7	658·7
Silver	1761·0	960·5
Gold	1945·5	1063·0
Copper	1981·5	1083·0
Nickel	2646·0	1452·0
Iron	2768·0	1520·0
Palladium	2820·0	1549·0
Platinum	3191·0	1755·0
Tungsten	5430·0	3000·0

The above values are used at the American Bureau of Standards for calibration purposes.

Passivity of Uranium.—The anodic behaviour of uranium has been investigated by U. Sborgi.* The metal was prepared by Moissan's method, and contained both carbon and nitrogen. The metal dissolves as anode in sulphuric, hydrochloric and nitric acids, probably with the valency 4. It becomes covered with an insulating layer in phosphates or alkalies, but true passivity is not observed, uranium being thus distinguished from all other metals of the sixth group.

Plastic Deformation and Annealing.—Very large crystals have been obtained by A. Portevin,† by prolonging the period of cooling of alloys from the liquid state over three days. Thus with an alloy of 97·8 per cent. of copper with 2·2 per cent. of aluminium, such large crystals were obtained that it was possible to cut a test-piece 17 millimetres high and of cross-section tapering from 12·8 × 7 millimetres to 9·5 × 7 millimetres. This was proved by etching to be a single crystal, with uniform orientation throughout. When compressed under a load of 600 kilograms, the first slip-bands appeared at an angle of 33° to the normal to the base. The plane thus developed is one of the cleavage planes of the grain used. The elastic limit varies with the direction of the stress. On each face the slip-bands follow sensibly the bisectrices of the dendritic axes. The elastic limit of an ordinary metal is thus a mere average. Annealing the specimen at 800° after testing produced numerous crystals, abundantly twinned, the number of grains being greatest where the pressure was greatest—that is, in the narrower portion of the specimen.

Solubility of Sulphur Dioxide in Fused Copper Alloys—A further study of the solubility of gases in metals is due to A. Sieverts

* *Zeitschrift für Elektrochemie*, 1913, vol. xix. p. 115.

† *Comptes Rendus*, 1913, vol. clvi. p. 320.

and E. Bergner,* the alloys used being those of copper with gold, silver, platinum, oxygen and sulphur. In all cases, as with pure fused copper, the solubility of sulphur dioxide increases with rise of temperature, and is proportional to the square root of the gas pressure. Oxygen and sulphur lessen the solubility, and the results may be accounted for by a partial reaction of the form $\text{SO}_2 + 6\text{Cu} \rightleftharpoons \text{Cu}_3\text{S} + 2\text{Cu}_2\text{O}$.

Specific Heat of Alloys.—The specific heats of bismuth-tin and bismuth-lead alloys, according to O. Richter,† are somewhat greater than the values calculated from the rule of mixtures, the differences being greater in the latter series. The electrical and thermal conductivities are smaller than those calculated from the rule of mixtures, but the ratio of electrical to thermal conductivity remains the same throughout. The evidence does not favour the view that free electrons are responsible for any appreciable fraction of the total heat capacity of the alloys.

Specific Heats at High Temperatures.—A method of determining specific heats of solids at high temperatures is described by M. von Pirani.‡ It depends on heating the substance electrically in a high vacuum, and suddenly increasing for a short time the supply of energy. The rise of temperature then depends on the specific heat. The specific heats of iron, tantalum and tungsten wires have thus been determined between 340° and 1400° . Iron has a well-defined minimum at 790° .

Strain-Disease in Metals.—Cohen's views on the so-called "strain-disease of metals" are criticized by E. B. Wolff.§ The view that cold-worked metals are in a metastable condition is an old one. It is not correct to assume that the metastable metal is converted into the stable modification by etching. All that the etching reagent does is to remove the superficial deformed layer. Thus, tinfoil does not exhibit any crystalline structure on etching; but if laid on glass, heated to fusion, and then etched, a crystalline structure is developed. Cohen's experiment, in which a cross, developed by etching, is transferred by contact at a high temperature to a polished surface of the same metal, is regarded as inconclusive, as the cross does not spread on the original sheet, as might be expected if the case were one of true infection; whilst the transfer is more easily accounted for as mechanical, and connected with the softening of the metal by heat. A sheet of tinfoil, laid on glass and heated until one corner fuses, is etched. It is found to make no difference if the tin is heated for some hours to 140° before etching, and etched tinfoil is not capable of infecting ordinary tinfoil at 140° .

In a short reply, E. Cohen || considers his conclusions to be confirmed by experiments with copper, to be published shortly, and promises to discuss the question in detail. Neither author refers to the work of Beilby, which contains an explanation of most of the observed facts.

* *Zeitschrift für physikalische Chemie*, 1913, vol. lxxxii. p. 257.

† *Annalen der Physik*, 1912 [iv.], vol. xxxix. p. 1590.

‡ *Berichte der deutschen physikalischen Gesellschaft*, 1913, vol. xiv. p. 1037.

§ *Zeitschrift für Elektrochemie*, 1913, vol. xix. p. 19.

|| *Ibid.*, p. 23.

Structure of Electrolytic Copper.—According to O. Faust,* the crystallites of electrolytic copper arrange themselves parallel with the lines of the current. The greater the current density and the smaller the concentration of copper in the electrolyte, the smaller are the crystallites. The crystallites are said not to continue the growth of the crystals present in the original cathode, whether this be of copper or of any other metal. The layer at first deposited consists of very numerous small crystals, but only a few of these continue to grow. The annealing of electrolytic copper has been followed by means of the microscope, and the orientation is revealed by straining until slip-bands appear. Electrolytic copper, like worked copper, develops twinning planes when annealed, indicating the presence of an internal stress, the existence of which is rendered probable by the known properties of thin electrolytically deposited films.

Structure of Electrolytic Deposits.—B. Wäser and E. H. Schulz † have continued their photographic examination of electro-deposited metals, including mercury, brass, and an alloy of nickel and magnesium. The photographs do not convey much novel information.

Surface Tension of Amalgams.—The surface tension of dilute amalgams has been measured by F. Schmidt, ‡ using a method which depends on the alteration of the wave-form when a jet of mercury escapes from an elliptical aperture, produced by the addition of other metals. The jets are photographed and measured by means of a micrometer. Up to 2 per cent. zinc, cadmium, thallium, gold, tin, and lead produce very little alteration in the surface tension of mercury; whilst even traces of lithium, barium, and calcium increase the surface tension largely. Sodium, potassium, rubidium, and caesium reduce the surface tension. The effect is found to be a periodic function of the atomic weight, and in any periodic group the surface tension of the amalgam increases with the melting point of the dissolved metal.

It may also be pointed out that the metals which either raise or depress the surface tension are those which form compounds with mercury, whilst the indifferent metals do not combine. A similar distinction has been observed in relation to the viscosity.

Thin Films of Platinum.—Very thin films of platinum, deposited in a high vacuum on quartz, have been studied by J. Robinson. § It is found that the photo-electric properties undergo a sudden change at a thickness of 10^{-7} centimetres, and that this limiting thickness is the same for either fast- or slow-moving electrons.

Twin Crystals and Hardness.—Experiments with copper-aluminium alloys by C. A. Edwards || show that the acicular structure of

* *Zeitschrift für anorganische Chemie*, 1912, vol. lxxviii, p. 201.

† *Elektrochemische Zeitschrift*, 1913, vol. xix, p. 304.

‡ *Annalen der Physik*, 1912 [iv.], vol. xxxix, p. 1108.

§ *Philosophical Magazine*, 1913 [vi.], vol. xxv, p. 115.

|| *Internationale Zeitschrift für Metallographie*, 1912, vol. iii, p. 179.

quenched alloys containing 10 to 13 per cent. of aluminium is essentially due to twinning. The twinning is not caused by the polishing process, as a polished specimen heated to 900° and quenched shows the same structure without etching. Examination under oblique illumination shows clearly that the acicular appearance is due to repeated twinning. Slip-bands, transverse to the twinning lines, also become evident. The hardening of such alloys by quenching is then explained as due to the formation of Beilby's vitreous phase by intercrystalline motion during the short period of cooling. The quenched alloy is found in one case to be very slightly denser than the same alloy in an annealed state.

Zinc and Cadmium Volatilization—Influence of Temperature and Pressure.—Practical tests by T. K. Nair and Thomas Turner * show that a small residual pressure considerably raises the distillation temperature of zinc. The rate of volatilization has therefore been determined, the method being to observe the loss with unit weight in fixed time (thirty minutes). Experiments were conducted with zinc in air, hydrogen, and carbon monoxide at selected pressures, and also with cadmium in air. Curves have been obtained showing the percentage of metal volatilized at temperatures and pressures covering a wide range.

The whole of the curves are parallel straight lines throughout the greater portion of their length, and it is found that:—

1. A certain definite temperature is required in order to give readily appreciable volatilization.

2. This critical temperature is raised by gaseous pressure, the effect of small additions being most marked.

3. When this critical temperature has once been reached, the rate of volatilization is independent of the initial pressure, or the nature of the gas, but it varies directly as the increase of temperature. If the initial rate be represented by R and the rate at any higher temperature by R^1 we have

$$R^1 = R + at.$$

4. Carbon monoxide raises the initial temperature slightly less than air, and hydrogen less than carbon monoxide, although at low pressures the differences are too small to be of much practical importance.

5. The pressure temperature curve for equal rate of volatilization is steep from 0 to 50 millimetres; after an abrupt change in direction, at 50 millimetres, it becomes a straight line from 80 millimetres, and much less steeply inclined. The straight lines for zinc and cadmium in this case are not parallel.

6. The last millimetre of pressure has seventy times the effect in lowering the temperature of effective distillation as compared with the removal of 1 millimetre, when starting from any pressure above 50 millimetres.

* *Proceedings of the Chemical Society*, 1913, vol. xxix. p. 151.

ELECTRO-METALLURGY.

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I.—ELECTRIC FURNACES.

Granular Chromium Resistances.—It is proposed by O. Dony-Henault * to use crushed metallic chromium as a heating material. For a crucible, a block of magnesia is hollowed out, so as to leave a space of 2 to 4 millimetres between the crucible and the outer wall. A ring of powdered graphite is added, and two carbon electrodes are plunged into the metal. A 100 cubic centimetres crucible is heated to the softening point of quartz by 15 amperes. The potential difference during working is 8 to 10 volts, but a high tension, say 110 volts, is required to start the current. A tube furnace may be constructed in similar manner.

Vacuum Electric Furnace.—A laboratory form of vacuum furnace is described by R. E. Slade,† and has been employed by him in his study of copper and cuprous oxide (p. 207). The heater is a platinum tube with walls 1 millimetre thick, 17·5 cubic millimetres long, provided with water-cooled brass terminals, and placed horizontally. It is packed in magnesia, and one end is left free to move under expansion. The interior is exhausted by means of a silver tube soldered to the plate closing one end; this is fixed gas-tight into a thick glass tube. In order to prevent the collapse of the platinum tube when exhausted, the whole furnace is enclosed under a cast-iron dome fastened to a cast-iron base, the enclosed space being exhausted by means of filter-pumps. The exhaust tube, thermo-couple leads, &c., pass out through holes in the iron base, joints being made by means of rubber stoppers. When exhausted, 350 amperes are required at 3 volts in order to heat to 1400°.

* *Comptes Rendus*, 1913, vol. clvi. p. 66.

† *Proceedings of the Royal Society*, 1912, vol. lxxxvii-A, p. 519.

II.—ELECTRIC SMELTING.

Electric Smelting of Copper and Nickel.—At the first meeting of the recently formed "Gesellschaft Deutscher Metallhütten und Bergleute" (essentially restricted in its scope to non-ferrous metallurgy), M. Stephan gave an account of experiments at the Girod electric steel works in Ugine, on the electric smelting of copper and nickel.*

Copper.—The ore came from the Belgian Congo. Five separate analyses gave CuO , 21·3–5·73; SiO_2 , 28·48–78·55; Al_2O_3 , 4–13; Fe_2O_3 , 4–16, and besides smaller impurities, from 2–7 per cent. CoO . Such ores are difficult to smelt in the water-jacketed copper blast furnaces, but do not offer any difficulty in the electric furnace. Furnaces similar to the Girod steel furnace were used.

Charcoal, coke, and anthracite, were used successfully as reducing agents with a limestone flux. Power used was not more than 200 kilowatts at from 30–150 volts.

Slag of the composition:

	Per Cent.
SiO_2	51·9
Al_2O_3	11·13
CaO	16·83
MgO	13·71
Fe_2O_3	3·55
MnO	0·94
CuO	0·46
CoO	0·87

begins to melt at 1250°C and is liquid enough at 1400° to allow the globules of copper to settle. At 1550° the slag flowed off freely. The pig copper produced in six different runs gave on analysis:

	Per Cent.
Copper	65–95
Iron	1–21
Cobalt	1–11

A lower temperature of working gave a purer product but a decreased yield owing to retention of copper by the slag.

A continuous run for several days aiming at slags of the above composition required 1000–1200 kilowatts per ton of ore. With an easily fusible ore the power consumption was only about 500 kilowatt-hours.

Nickel.—A small 220 kilowatt furnace treated 3 tons of ore in 28 hours, producing 350 kilos of a ferro-nickel having the following composition:

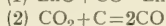
	Per Cent.
Nickel	41·5
Iron	51·61
Silicon	4·33
Aluminium	0·81
Carbon	1·34
Sulphur	0·04

* *Metallurgical and Chemical Engineering*, 1913, vol. xi. pp. 22–23.

Electric Smelting of Nickel.—E. F. Gray,* British Consul at Christiania, sends information respecting a new type of electric furnace for reducing nickel from garnierite. This furnace has been designed by Raeder, acting for the Christiansand Nickel Refining Works, after considerable research and testing work.

Electric Zinc Smelting.—The fact that electrical methods for smelting zinc ores have so far not been commercially successful is attributed by F. Louvrier † to the excessive amount of carbon dioxide produced in contact with the zinc vapour previous to its condensation. Oxidation of the zinc by the carbon dioxide takes place, leading to the production of “blue powder” and resulting in a poor yield of metal.

Considering the two equations :



the presence of carbon dioxide along with the zinc vapour in the condenser is to be ascribed to the incompleteness of the reaction expressed by equation (2). In the case of electric smelting, this results from the too rapid production of carbon dioxide in the limited space of the heated zone, with the consequence that a considerable proportion escapes reduction either by passing too quickly to cooler portions of the furnace or, in the case of small furnaces, by meeting an insufficient quantity of carbon as well as too high a temperature. The conditions, chiefly with regard to the zone of reduction, which must obtain in smelting furnaces to ensure complete reduction of the carbon dioxide are indicated.

* *Board of Trade Journal*, 1912, vol. lxxix. p. 516.

† *Metallurgical and Chemical Engineering*, 1912, vol. x. pp. 747-749.

ANALYSIS, TESTING, AND PYROMETRY.

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I.—ANALYSIS.

Assay of Impure Mattes.—In assaying impure mattes, P. S. Harrison* finds that the iodide assay for copper is more suitable and gives more reliable results than the electrolytic assay. It is also quicker.

Detection of Nickel in Alloys.—According to V. Fortini,† a polished surface of an alloy containing nickel may be tested by oxidizing the surface lightly with a small oxidizing flame, cleaning with ether, and applying a drop of the testing solution. This is prepared by dissolving 0·5 gram of dimethyl-glyoxime in 5 cubic centimetres of alcohol by adding 5 cubic centimetres of concentrated ammonia. This solution, which keeps well, reacts quickly with nickel oxide, and the red precipitate becomes visible before the solution has time to become appreciably darkened by copper.

Separation of Arsenic from Tungsten.—The estimation of arsenic in presence of tungsten, according to S. Hilpert and T. Dieckmann,‡ is exceptionally difficult, owing to the formation of complex acids. The distillation method for arsenic has been tried, using cuprous chloride as the reducing agent, but the arsenic found is always low, the error increasing with the proportion of tungsten. The arsenic is retained by the tungstic acid by adsorption, and not as a definite compound. The error is remedied by carrying out the distillation in two parts, and adding solid potassium hydroxide to the residue in the flask after the first distillation, until alkaline, and then adding hydrochloric acid and

* *Engineering and Mining Journal*, 1913, vol. xcv. p. 283.

† *Chemiker-Zeitung*, 1912, vol. xxxvi. p. 1461.

‡ *Berichte der deutschen chemischen Gesellschaft*, 1913, vol. xli. p. 152.

again distilling. The surface of the tungstic acid is in this way destroyed and the arsenic liberated.

Variation in Assaying Gold Ores.—An account of the variations found in assays at the Alaska Treadwell mill is given by W. P. Lass.* The results are summarized of a number of special assays of three different grades of ore, viz., the mine samples and mill feed, the concentrates and the tailings. The following examples illustrate the character of the variations observed:—

1. *Concentrates.*—Ten different samples, all unknown to the assayer, were crushed to pass through a 120-mesh sieve, and duplicate assays made, $\frac{1}{2}$ A.T. being taken in each case. The average of the 20 separate assays was \$68.79 per ton, and the average variation in duplicate assays was \$5.21 per ton or 7.6 per cent.

2. *Mine and Mill Samples.*—Twenty-eight different samples, all unknown to the assayer, were crushed to pass through a 100-mesh screen, and duplicate assays made, 1 A.T. being taken in each case. The average of the 56 separate assays was \$3.46 per ton, and the average variation in duplicate assays was \$1.43 per ton or 41.3 per cent.

3. *Tailings from the Mill.*—Ten different samples, all unknown to the assayer, were crushed to pass through a 100-mesh screen and duplicate assays made, $2\frac{1}{2}$ A.T. being taken in each case. The average of the 20 separate assays was 32.7 cents per ton, and the average variation in duplicate assays was 6.7 cents per ton or 20.6 per cent.

In explanation of the variations met with, the author makes some calculations to show the effect of a single particle of gold on the assay value. Thus in 1 A.T. of cubic particles of the same dimensions as the openings of a 100-mesh screen there are at least 5,348,811 particles. If one of these particles happened to be fine gold, it would increase the assay result by \$1.12 per ton. The greater the variation in value between the particles, the greater is the error, a \$1 particle in the mill feed having a greater effect than in the concentrates. The variations in assays on the mine samples and mill feed is greater than the variation in assays on the tailings samples, and this is accounted for by the fact that the free gold is high in the former and is to a great extent removed in the latter. It is, however, pointed out that, although the average variation may be great, the average value of the samples remains approximately the same.

Volumetric Estimation of Zinc.—According to V. Senher and C. C. Meloche,† the presence of lead is without influence on the titration of zinc by ferrocyanide solution, as usually carried out—that is, in hydrochloric acid solution. Lead itself can only be titrated with ferrocyanide in acetic acid solution, a small quantity of mineral acid being sufficient to prevent precipitation.

* *Mining Magazine*, 1913, vol. viii. p. 57.

† *Journal of the American Chemical Society*, 1913, vol. xxxv. p. 134.

II.—TESTING.

Notched-Bar Impact Tests.—A number of papers presented to the Sixth International Congress for Testing Materials held in New York in September last were specially devoted to the question of notched-bar impact tests; an account of them and of some of the ideas advanced in the discussions is given by W. Rosenhain.*

At the previous Congress held in Copenhagen in 1909, a proposal that one particular type of machine should be adopted as international standard was negatived. Standard dimensions of 10×10 millimetres and 30×30 millimetres in cross section were, however, decided upon for the test-pieces, the other dimensions being based on the assumption that the law of similarity held good and that the same "specific work of rupture" would be found for a given material if the total work of rupture were referred to unit of ruptured area, so long as the test-pieces were geometrically similar. A committee appointed to further investigate the question of impact tests presented to the Congress in New York a report prepared by G. Charpy. The results of experiments by members of this committee are quoted as leading to the conclusion that "the resilience or specific work of rupture when referred to one square centimetre of the section of rupture varies for one and the same metal according as the value is determined on a test-piece measuring 30×30 millimetres or one measuring 10×10 millimetres." The smaller test-piece always gave a value lower than the larger one.

With regard to the machine itself, the view is expressed in the report that the exact manner of applying the impact is not vital to the results. Accuracy, reliability, and manner of handling are of principal importance—frictional and vibrational losses of energy are serious sources of error, and methods of standardizing and calibrating impact testing machines should be established.

The committee finally urges the need of systematic correlation between the results of impact tests and behaviour in practice, and proposes that a large amount of such information should be collected by the general use of a form of return giving full particulars as to the nature and circumstances of each failure, the composition, mode of manufacture, and micro-structure, &c., of the material.

Papers following this report dealt rather with the report and resolutions passed upon this subject at the previous Congress in Copenhagen. C. Frémont in his paper deprecates the use of the heavy pendulum type of machine, and criticizes the size of test-piece and character of the notch. Important evidence in favour of the use of the Frémont test was given by M. Derihon. Other papers contributed by A. Gessner (Pilsen), the Testing Laboratory of the Paris-Lyons-Mediterranean Railway and N. Davidenkoff (St. Petersburg) dealt with the influence of varying types of fracture, &c., a recording half-hammer apparatus, and direct tensile impact machines in which the specimen falls with two tups.

* *Engineer*, 1913, vol. cxv. pp. 110-112.

T. E. Stanton in his paper describes the various types of testing apparatus devised by him at the National Physical Laboratory, including the machine for direct alternations of stress, the rolling fatigue test, the single blow impact and the repeated blow impact test on notched bars. Finally, a paper by Prince A. Gagarin described a series of attempts to obtain autograph stress-strain diagrams for impact tests.

In conclusion, the general feeling expressed at the Congress was that although it would as yet be difficult to introduce impact tests into specifications, owing to the difficulty of obtaining consistent results from different machines and sizes of test-pieces, enough had been done to show that some such form of "brittleness test" over and above the ordinary tensile or static test was required in order to secure satisfactory qualities of material.

The special committee entrusted with the matter was requested to present to the next Congress definite proposals upon the following points:—

Height of drop, weight of anvil, method of calibration, form of supports for test-bars, and dimensions of the notch for small test-bars.

III.—PYROMETRY.

Calibration of Optical Pyrometers.—A simple "black body" for use in calibrating optical pyrometers is described by P. D. Foote.* The arrangement consists of a tall cylindrical graphite crucible 20 centimetres high, by rather more than 5 centimetres internal diameter, closed by a lid (kept in position by a screw thread), the central portion of which is continued as a hollow cone passing down into the interior of the crucible, and having at its apex a small cylindrical chamber 2 centimetres diameter by 2 centimetres deep, which acts as the "black body." The bottom of the small chamber is about 16 centimetres from the top of the crucible. The internal diameter of the cone at its base in the lid is about 1.25 centimetres, and at the entrance to the small chamber 0.5 centimetres. The crucible being filled with metal which thus surrounds the hollow cone and small chamber, melting and freezing points are readily obtained, the pyrometer being focussed on to the entrance to the small chamber at the apex of the cone.

The arrangement is particularly intended for use with the Holborn-Kurlbaum instrument, but may be used with other types, provided the cone of rays coming from the black body entrance is not intercepted by the walls of the cone, and that the aperture is large enough to fill the optical system of the instrument.

Fixed Points for High Temperature Measurements.—A description is given by A. Day and R. Sosman† of research work con-

* *Metallurgical and Chemical Engineering*, 1913, vol. xi. pp. 97–98.

† *Journal de Physique*, 1912, vol. ii. (5th Series), pp. 727, 831, 899.

ducted to determine fixed points between 1100° C. and 1600° C., which shall be useful for accurate calibration of thermo-electric couples.

The work comprises the making of a suitable gas thermometer and the standardization of a number of platinum, platinum-rhodium thermo-couples against this thermometer; finally, the temperatures of a number of very useful fixed points were obtained, using the couples already standardized against the gas thermometer.

The authors used two constant-volume nitrogen gas thermometers for this purpose with a capacity of 200 cubic centimetres, the bulb being of platinum-iridium (10 per cent.), or platinum-rhodium (10 per cent.), the latter material being found to wear better.

The electric furnace in which the couples were standardized against this thermometer was wound with a resistor of platinum wire, and the pressure of air inside the furnace was regulated so as to be always approximately equal to that in the gas thermometer, thus avoiding undue strain on the metal bulb. The winding is laid on the inside of the furnace tube in three independent sections, an arrangement which secures even heating of the central portion.

The furnace is water cooled, and, working on vertical guides, it is raised or lowered as required, the gas thermometer itself remaining fixed during a series of tests.

The bulb of the gas thermometer was connected by a platinum capillary to a mercury manometer, a special feature of which was the method of closing the short arm of the U-tube, which reduced the volume of cold gas to a minimum. A very careful series of determinations of the expansion of the platinum alloys used for the reservoir was made, so that accurate corrections could be introduced up to the highest temperatures attained in the work. The thermo-electric apparatus is fully described, and the results of contamination of the couple wires by metallic vapours was experimentally investigated. This contamination constitutes the most likely source of error, and it is obviated by testing the working couples against a standard immediately after each series of readings with the gas thermometer. Results are given of a very careful investigation to discover which are the best positions for the three couples used in conjunction with the gas thermometer.

The method of taking readings is described, and results obtained in standardizing the couples against gas thermometers both of platinum rhodium and of platinum-iridium are given. The last part of the work relating to the determination of fixed points, discusses the best materials and most suitable conditions for ensuring accurate repetition of the fixed point temperatures.

Two silicates, diopside and anorthite, are included in the fixed points; they are said to give very constant readings for their melting points. Some of the results obtained are given in the table below:—

Material.	Point.	Atmosphere.	Crucible.	Temperature. Degrees C.	Thermo- dynamic Scale.
Cadmium . . .	Melting and freezing.	Air.	Graphite.	320.8 ± 0.2	320.9
Zinc	Do.	Air.	Do.	419.3 ± 0.3	419.4
Antimony . . .	Do.	CO.	Do.	629.8 ± 0.5	630.0
Aluminium . . .	Freezing.	CO.	Do.	658.5 ± 0.6	658.7
Silver	Melting and freezing.	CO.	Do.	960.0 ± 0.7	...
Gold	Do.	CO.	Do.	1062.4 ± 0.8	...
Copper	Do.	CO.	Do.	1082.6 ± 0.8	...
Diopside (pure) .	Melting.	Air.	Platinum.	1391.2 ± 1.5	...
Nickel	Melting and freezing.	Hydrogen and nitrogen.	Magnesium and magnesia aluminate.	1452.3 ± 2.0	...
Cobalt	Do.	Do.	Magnesia.	1489.8 ± 2.0	...
Palladium . . .	Do.	Air.	(Pure magnesia.)	1549.2 ± 2.0	...
Anorthite . . .	Melting.	Air.	Platinum.	1549.5 ± 2.0	...

Micro-Pyrometer.—An instrument is described by G. K. Burgess * by means of which the melting point of a few hundredths of a milligram of metal may be determined with accuracy. The microscope and pyrometer form a single instrument. The metal is heated electrically on a platinum strip, and the eyepiece of the microscope contains a small glow lamp, the current through which is adjusted until the filament is equal in brightness to the strip. A red monochromatic light filter is used. With such metals as gold or nickel an accuracy of $1-2^\circ$ may be obtained.

Temperature Measurement.—Thermocouples of various metals, the radiation pyrometer depending for its readings on a small thermocouple, and resistance thermometers are discussed by C. Burton Thwing,† and their uses and limitations indicated.

Thermocouples.—The first to be used was that of Le Chatelier, and consisted of a wire of platinum and one of platinum containing 10 per cent. iridium. Rhodium has largely replaced iridium in these couples, giving decreased sensitiveness but greater constancy in continuous use particularly at high temperatures. The platinum thermocouples may be used up to temperatures in the neighbourhood of 1600°C. for short intervals. Prolonged exposure to such high temperatures, however, causes a fall in electromotive force due to changes in the composition of the wires brought about by volatilization of the constituent metals.

For temperatures up to 1000°C. , thermocouples of base metals are in many respects superior to those of platinum. They are in general much

* *Physikalische Zeitschrift*, 1913, vol. xiv. p. 158.

† *Metallurgical and Chemical Engineering*, 1913, vol. xi. pp. 36-38.

more sensitive due to the higher electromotive force generated at the hot junction. This enables more resistance to be used in the galvanometer circuit, and thus minimizes the error caused by changes in resistance of the couple due to variations of temperature or depth of immersion. In consequence of their cheapness thicker wires may be used which again tends to counteract the above error. For couples required to be used up to 1100°C . a nickel-chromium (10 per cent. chromium) alloy as positive element in conjunction with an alloy of nickel containing small percentages of various other elements is most suitable. Such a couple has an electromotive force about $3\frac{1}{2}$ times that of platinum at 1100°C .

Up to 900°C . the copper or iron-constantan (nickel 41, copper 59 per cent.) couple gives a high and very constant electromotive force, and has the additional advantage of a small coefficient of resistance.

Limitations to the use of thermocouples as such, in works practice, are due to their slowness of action, the small amount of energy generated which necessitates delicate measuring instruments, "cold junction" errors, &c.

Radiation Pyrometer.—In these instruments of which the Fery is a good type, the energy radiated from a portion of the surface of the body whose temperature is to be measured is focussed by a concave mirror on to the junction of a sensitive thermocouple. These instruments are capable of a considerable degree of accuracy, and are available for temperatures too high for thermocouples, for situations not easily accessible such as interiors of large furnaces, for material in motion such as masses of steel passing through rolls, &c. A simplified form of one of these instruments attains its correct reading in five seconds.

Resistance Pyrometer.—This instrument, which depends for its indications on the electrical resistance of a coil of platinum or other metal wire, has been used for all ranges of temperature from that of liquefied gases to temperatures as high as 1100°C . At high temperatures the problem of protecting the coil from mechanical damage and contamination becomes a serious one. A platinum coil must be protected with a porcelain tube and an additional covering of nickel, and is an expensive instrument.

For the lowest temperatures up to 200°C . resistance coils of pure nickel are used, and the instrument is capable of accuracy comparable with that of the best thermometers.

Selection of type of Pyrometer.—One of the first considerations is the required range of temperature. For temperatures with a maximum range above 1500°C . the radiation type is the only one of the three available. The lower limit of these instruments is about 500°C .

With an upper limit of 1500°C . choice may be had between the radiation pyrometer and the platinum thermocouple, and up to 1200°C . we may include the nickel-chromium couple.

With a maximum temperature of 1000°C . the iron-constantan thermocouple would come first in consideration with the platinum resistance type also available, whilst for temperatures below 200°C . the iron-constantan couple or nickel resistance-pyrometer would be suitable.

Other factors to be considered in choosing an instrument are the size of the body whose temperature is to be measured, the rate of fluctuation of temperature which may be encountered, &c.

Tungsten-Molybdenum Thermocouple.—The thermal electromotive force of this couple has been investigated by E. F. Northrup,* over a temperature range of 0° C.—1000° C.

Wire of 20 B. & S. gauge was obtained from the General Electric Co. Temperatures were measured with a platinum-rhodium thermocouple and electromotive force with a Leeds-Northrup potentiometer. The equation—

$$E = 4.61t - 0.00436t^2$$

microvolts is correct over the range determined, with an error of less than 4 per cent.

The electromotive force is a maximum at 530° C., and is zero at 1060° C. (melting point of gold = 1062° C.), the current in this range flowing from tungsten to molybdenum through the hot junction.

Assuming the above equation to hold up to 2200° C., the electromotive force at this temperature would be 10,960 microvolts.

The author does not despair of finding a protective case for the couple at such temperatures. For laboratory work oxidation may be prevented by using a neutral gas atmosphere.

* *Metallurgical and Chemical Engineering*, 1913, vol. xi. p. 45.

FURNACES AND FOUNDRY METHODS.

Briquetting Metal Turnings and Borings.—A description is given of briquetting plants made by the Hochdruckbrikettierung Ges. m.b.H., Berlin (J. W. Jackman & Co., Caxton House, Westminster).^{*} These machines are designed to overcome the difficulties encountered in melting down borings and turnings of brass, gun-metal, and bronze (and also iron and steel) for foundry purposes. The melting of such turnings entails very considerable losses by oxidation, but when in the form of briquettes such losses are much reduced, and the time of melting is greatly decreased.

The machine for making the briquettes consists of a rotating table carrying the moulds into which the metal scrap is automatically fed. It is then pressed on both sides by two vertical plungers, top and bottom, working under very great hydraulic pressure. The finished briquette is pushed out of the mould, an empty mould meanwhile taking its place between the plungers.

It is claimed that the plant works automatically, three men being sufficient to run it. The capacity varies from 1 to 3 tons of briquettes per hour.

The briquettes are cylindrical in shape, and are strong enough to stand very rough handling.

The turnings and borings may require to be cleaned, and if very long they must be broken up a little in a disintegrator before entering the press.

Another briquetting plant for metal borings, made by Samuel Denison and Sons of Leeds, is described.[†] The machines are fed automatically, and it is claimed that the cost of briquetting may be as low as 1s. 8d. per ton. Instances of reduction of melting losses by briquetting are given in the case of brass borings (melting loss 3 to 4·5 per cent.) and of aluminium (loss of 15·3 per cent.).

A number of results obtained by melting down unbriquetted brass and bronze turnings and chips are given by R. A. Wood.[‡] The method adopted consists in introducing the turnings gradually into a hot covered crucible placed in the melting furnace. The turnings are only introduced into the crucible in small amounts, so that they are melted almost immediately, thus reducing loss of metal as much as possible. The actual examples given show melting losses of from $2\frac{1}{2}$ to $7\frac{1}{2}$ per cent.

^{*} *Engineering*, 1913, vol. xcv. p. 139.

[†] *Ibid.*, 1912, vol. xciv. p. 737.

[‡] *Metal Industry*, 1912, vol. iv. p. 408.

Influence of Casting Temperature.—H. W. Gillet * gives the results of a series of tensile tests on manganese bronze of following composition :—

	Per Cent.
Copper	56.00
Zinc	41.00
Iron	1.50
Tin	0.90
Aluminium	0.45
Manganese	0.15

The test-bars were cast at various temperatures from large melts, and were submitted to mechanical tests both with and without previous machining. The dimensions of the bars were $\frac{1}{2}$ inch diameter and 2 inches long over the breaking section. Some of the results are given below :—

	Pouring Temp., Degrees F.	Tensile Strength.	Elastic Limit.	Elongation, per Cent.
Test-bars cast to size . . .	2,125	79,000	38,000	28.0
	2,000	76,500	42,600	17.0
	1,900	75,200	42,000	18.0
	1,825	68,300	40,000	14.0
	2,125	77,300	41,000	35.0
Test-bars machined to size .	2,000	76,900	41,500	34.0
	1,900	76,500	41,100	30.0
	1,825	76,000	41,700	24.0

These results do not agree with the view generally held that pouring temperature should be as low as possible, but the author believes that at the lower pouring temperatures the metal became unsound on account of bad feeding.

1950° to 2000° F. is suggested as the best average casting temperature for the alloy under consideration.

Lead Filter for Zinc Furnaces.—The Shortman process of extracting high grade spelter from galvanizers' residues is described.† It consists in heating the residues, containing about 3 per cent. of zinc, in ordinary retort furnaces, in the mouth of which is placed a small fireclay sleeve packed with anthracite or coke. In this sleeve the lead is condensed, and only pure zinc finds its way into the condenser. The filter can be used for two tappings, after which it must be recharged with colse. The spelter thus obtained is from 99.9 to 99.95 per cent pure zinc.

Pyrometers for Foundry Use.—The use of thermocouples and optical pyrometers in foundries is described by R. Schwann,† with particulars of the methods of use.

* *Metal Industry*, 1912, vol. iv. p. 452.

† *Ibid.*, 1912, vol. iv. p. 355.

‡ *Giesserei-Zeitung*, 1913, vol. x. pp. 133, 169.

Test-Bars for Non-ferrous Alloys.—An investigation of the suitability of a number of different castings for obtaining tensile test-pieces of alloys has been made by J. L. Jones.* Twelve different patterns of bar were experimented with, one of which was a chill casting in an iron mould. From the eleven sand-casting patterns bars were prepared both with and without risers, and the castings machined to size and broken. Tests were made on two alloys, a manganese bronze and a red brass, but no information is given regarding the casting temperature. The effect of quenching in lowering the ductility of manganese bronze is discussed with relation to the microstructure. The author concludes that, for big work, hollow-drilled test-bars $\frac{7}{8}$ inch diameter by $4\frac{1}{2}$ inches long are the best type of test-piece. For smaller castings the test-bars may be cast either attached to the work itself or separately in suitable chill or sand moulds, the best patterns of which are indicated in the paper. If sand castings of the test-bars are made heavy risers should always be used to ensure sound metal.

* *Metal Industry*, 1912, vol. iv. p. 490.

S T A T I S T I C S.

Aluminium in India.—A new industry in S. India is the manufacture of aluminium articles.* Imports of this metal into the Madras Presidency for year ending March 1912 amounted to \$204,039.

Production of Manganese.—The total of the world's production of manganese † during 1911 was 1,485,746 tons; nearly three-quarters of this were obtained from India and the Caucasus.

Canadian Mineral Production for 1912.—In a preliminary report of the Canadian Department of Mines ‡ the total mineral production for 1912 is estimated at \$133,127,489, of which \$61,177,980, or nearly 46 per cent., is credited to metals. The production of copper, gold, lead, nickel, and silver for 1911 and 1912 is as follows:—

	1911.	1912.
Copper (lb.)	55,648,011	77,775,600
Gold (ozs.)	473,159	607,609
Lead (lb.)	33,784,969	35,463,476
Nickel (lb.)	34,098,744	44,841,542
Silver (ozs.)	32,559,044	31,931,710

Colorado Mineral Production for 1911.—According to Charles W. Henderson, § of the United States Geological Survey, the value of the total output of gold, silver, copper, lead, and zinc, was \$32,418,218 as compared with \$33,673,879 for 1910.

Electro-Metallurgy in 1912.—According to R. Pitaval || there has been a great increase in the consumption of aluminium during 1912. A great French trust has been formed, *L'Aluminium Français*, the production of which now amounts to about 15,000 tons, and many more factories are to be erected. The sales of ferro-silicon through the international bureau have exceeded 30,000 tons, and the use of ferro-titanium

* *Metal Industry*, 1912, vol. iv. p. 495.

† *Ibid.*, p. 497.

‡ *Engineering and Mining Journal*, 1913, vol. xcv. p. 560.

§ *Mines and Minerals*, 1912, vol. xxxiii. p. 286.

|| *Journal du Four Electrique*, 1913, vol. xxii. p. 1.

is on the increase. Several firms are experimenting with electric furnaces for zinc smelting, including the Vielle Montague. The manufacture of ferro-nickel in the electric furnace has undergone a check in New Caledonia, but is making progress in Norway. On the Congo the electric furnace is superseding the older process for the treatment of copper ores.

German Zinc Industry.—The zinc industry of Germany is described * as being more satisfactory during 1912 than in the previous year.

The average price obtained by the Zinc Syndicate during 1912 was about £1 6s. 7d. per ton, and the total production of zinc in Upper Silesia for this year was about 165,000 metric tons.

Gold Production in the United States.—The value of the gold produced in the United States for 1912 † is estimated at \$91,685,168, as compared with \$96,890,000 for 1911. The output of the five principal gold producing states is estimated as follows:—

	\$
California	19,988,486
Colorado	18,791,710
Alaska	17,398,946
Nevada	13,331,680
South Dakota	7,795,680

Metal Trades of Germany in 1912.—The German metal industries have been very prosperous during 1912.‡

The consumption of copper during the year showed an increase of 25,000 metric tons over that of 1911.

Consumption of lead was 229,000 metric tons—a decrease of 700 metric tons over that of 1911

The production of tin was 12,000 metric tons and consumption 21,000 metric tons.

Mineral Production of New South Wales.—The New South Wales Department of Mines § gives the total value of the mineral output of the State during 1911 as £9,758,006, an increase of more than £1,000,000 on that of 1910.

The output for both years of some of the products is given below:—

* *Board of Trade Journal*, 1913, vol. lxxx. p. 94.

† *Mines and Minerals*, 1913, vol. xxxiii. No. 7, p. 365.

‡ *Board of Trade Journal*, 1913, vol. lxxx. p. 151.

§ *Ibid.*, 1912, vol. lxxix. p. 360.

	1910.	1911.
Copper (ingot matte and ore), (tons)	12,890	12,100
Gold (ozs., fine)	188,857	181,121
Lead (pig, &c.) (tons)	21,195	17,276
Silver lead (ore concentrates, &c.) (tons)	317,697	338,468
Silver (ingot and matte) (ozs.)	1,773,913	1,767,496
Tin (ingot and ore) (tons)	1,868	1,929
Wolfram (tons)	165	283
Zinc (spelter and concentrates), (tons)	468,627	516,378

Mineral Production of Servia.—It is stated* that the total mineral output of Servia during 1911 amounted to 15,400,000 dinars as compared with 12,800,000 dinars in 1910. Some items are given below :—

	1911.	
	Amount.	Value,
Copper ore	7,023 metric tons	8,000,000 dinars
Coal	235,058 „ „	3,775,776 „
Gold	422 kilogrammes	1,500,000 „

25 dinars=£1. Metric ton=1 kilogramme.

Minerals and Metals in Austria-Hungary.—The total value of products mined in Austria in 1911 is given† as 320,107,395 kronen and that of smelted material as 155,669,109 kronen, both showing a substantial increase over the figures for the previous year. The production of some of the chief minerals is given below :—

	1910.	1911.
	(Double Centners.)	(Double Centners.)
Gold ore	317,440	296,470
Silver ore	236,286	241,428
Zinc ore	346,365	321,657
Graphite	331,313	415,993
Lignite	251,328,547	252,653,338
Coal	137,739,851	143,798,172

Krone=10*d.* Double centner=220·5 lbs.

The amounts of lead and of zinc smelted during 1911 were respectively 180,970 double centners and 157,663 double centners.

* *Board of Trade Journal*, 1912, vol. lxxix. p. 411.

† *Ibid.*, p. 460.

Platinum and Allied Metals in the United States.—The total quantity of refined platinum* produced in refineries in the United States was 29,140 ozs. fine, of which only about 940 ozs., value \$40,890, was derived from domestic sources of various kinds. The entire output (628 ozs.) of crude platinum in the United States was recovered from placed mines in California and Oregon, the greater part coming from California. In addition some was recovered from gold and silver bullion obtained from certain mines.

Notes are also given of an ore containing platinum with copper, gold, and some palladium from the New Rambler Mine, Wyoming.

Production of Metals in the United States. †—

	1910.	1911.	1912.
Copper (lb.)	1,086,249,983	1,083,856,371	1,242,836,024
Gold (dollars)	96,269,100	96,890,000	91,635,186
Lead (short tons)	392,704	400,958	418,224
Nickel ¹ (lb.)	32,050,032	29,545,967	33,311,233 ²
Quicksilver (flasks)	22,418	21,500	25,147
Silver (ozs.)	57,137,900	60,399,400	62,369,901
Zinc (short tons)	277,065	295,836	347,922

¹ Imported and refined in U.S.A.

² First ten months only of 1912.

The production of tungsten is estimated at 1290 tons, 60 per cent. concentrate. The vanadium output is equivalent to 300 tons of metallic vanadium. Quicksilver shows the largest production in six years, being 25,147 flasks of 74 pounds each.

Russian Copper in 1912.—It is stated ‡ that the total production of copper in Russia during 1912 was 2,048,233 pouds, contrasted with 1,571,879 pouds in 1911. (1000 pouds = 16 tons (approx.)) The Ural district is specially notable for increased production.

Transvaal Gold Production.—The yield for the month of October 1912 was 768,681 fine ounces gold, § being about 60,000 ounces more than during the same period of 1911. The yield for the month of November 1912 was 757,337 fine ounces gold.

Zinc Production at Broken Hill.—The production of zinc concentrate in the Broken Hill district for 1912 is estimated by Theodore J. Hoover || to be 440,000 tons, a decrease of 60,000 tons as compared

* *Mines and Minerals*, 1913, vol. xxxiii. No. 7, p. 389.

† *Engineering and Mining Journal*, 1913, vol. xciv. p. 49.

‡ *Board of Trade Journal*, 1913, vol. lxxx. p. 517.

§ *Metallurgical and Chemical Engineering*, 1913, vol. xi., pp. 94, 167.

|| *Mining Magazine*, 1913, vol. viii. pp. 47-48.

with 1911. A curve is given showing the production of zinc concentrate for this district since 1900, together with a forecast of probable future production. It is pointed out that the great increase in production, which began in 1906, as a result of the introduction of the flotation process, had no effect on the price of the metal.

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SECTION III.

MEMORANDUM AND ARTICLES OF ASSOCIATION AND LIST OF MEMBERS.

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The Companies (Consolidation) Act, 1908

Memorandum of Association

OF

THE INSTITUTE OF METALS

1. The name of the Company is THE INSTITUTE OF METALS.
2. The Registered Office of the Association will be situate in England.
3. The objects for which the Association is established are:—
 - (a) To take over the whole or any of the property and assets, which can be legally vested in the Association, and the liabilities and obligations of the unincorporated Society known as the Institute of Metals, and, with a view thereto, to enter into and carry into effect, with or without modifications, the agreement which has already been engrossed and is expressed to be made between Gilbert Shaw Scott of the one part, and the Association of the other part, a copy whereof has, for the purpose of identification, been signed by three of the subscribers hereto.
 - (b) To promote the science and practice of non-ferrous metallurgy in all its branches, and to assist the progress of inventions likely to be useful to the members of the Association and to the community at large.

- (c) To afford a means of communication between members of the non-ferrous metal trades upon matters bearing upon their respective manufactures other than questions connected with wages, management of works, and trade regulations.
- (d) To facilitate the exchange of ideas between members of the Association and between members of the Association and the community at large by holding meetings and by the publication of literature, and in particular by the publication of a Journal dealing wholly or in part with the objects of the Association.
- (e) To establish Branches of the Association either in the United Kingdom or abroad to be affiliated to the Association upon such terms and conditions as may be deemed advisable, but so that all such Branches shall prohibit the distribution of their income and property by way of dividend or otherwise amongst their members to an extent at least as great as is imposed on the Association by virtue of Clause 4 hereof.
- (f) To acquire by purchase, taking on lease or otherwise, lands and buildings and all other property real and personal which the Association, for the purposes thereof, may from time to time think proper to acquire and which may lawfully be held by them, and to re-sell, under-lease, or sub-let, surrender, turn to account, or dispose of such property or any part thereof, and to erect upon any such land any building for the purposes of the Association, and to alter or add to any building erected upon such land.
- (g) To invest and deal with the moneys of the Association not immediately required in such manner as may from time to time be determined.

- (h) To borrow or raise or secure the payment of money in such manner as the Association shall think fit, and in particular by Mortgage or Charge upon any of the property of the Association (both present and future), and to redeem and pay off any such securities.
- (i) To undertake and execute any trusts, the undertaking whereof may seem desirable.
- (k) To establish and support, or aid in the establishment and support of associations, institutions, funds, trusts, and conveniences calculated to benefit employees or ex-employees of the Association or the dependents or connections of such persons, and to grant pensions and allowances and to make payments towards insurances, and to subscribe or guarantee money for charitable or benevolent objects or for any Exhibition or for any public, general, or useful object.
- (l) To establish, form, and maintain a library and collection of metals, alloys, models, designs, and drawings, and other articles of interest in connection with the objects of the Association, or any of them.
- (m) To give prizes or medals as rewards for research, for inventions of a specified character, or for improvements in the production or manufacture of non-ferrous metals and their alloys, and to expend money in researches and experiments, and in such other ways as may extend the knowledge of non-ferrous metals and their alloys.
- (n) To do all things incidental or conducive to the attainment of the above objects or any of them.

Provided that the Association shall not support with its funds or endeavour to impose on or procure to be observed by its members any regulations which, if an object of the Association, would make it a Trade Union.

Provided also that in case the Association shall take or hold any property subject to the jurisdiction of the Charity Commissioners or Board of Education for England and Wales, the Association shall not sell, mortgage, charge, or lease the same without such authority, approval or consent as may be required by law, and as regards any such property the Council or Trustees of the Association shall be chargeable for such property as may come into their hands, and shall be answerable and accountable for their own acts, receipts, neglects, and defaults, and for the due administration of such property in the same manner and to the same extent as they would as such Council or as Trustees of the property of the Association have been if no incorporation had been effected, and the incorporation of the Association shall not diminish or impair any control or authority exercisable by the Chancery Division, the Charity Commissioners, or the Board of Education over such Council or Trustees, but they shall, as regards any such property, be subject jointly and separately to such control and authority as if the Association were not incorporated. In case the Association shall take or hold any property which may be subject to any trusts, the Association shall only deal with the same in such manner as allowed by law having regard to such trusts.

4. The income and property of the Association whencesoever derived shall be applied solely towards the promotion of the objects of the Association as set forth in this Memorandum of Association, and no portion thereof shall be paid or transferred directly or indirectly by way of dividend, bonus, or otherwise howsoever by way of profit, to the members of the Association. Provided that nothing herein contained shall prevent the payment in good faith of remuneration to any officers or servants of the Association, or to any member of the Association, in return for any services actually rendered to the Association, but so that no member of the Council or governing body of the Association shall be appointed to any salaried office of the Association or any office of the Association paid by fees, and that no remuneration or other benefit in money or money's worth shall be given to any

member of such Council or governing body except repayment of out of pocket expenses and interest at a rate not exceeding 5 per cent. per annum on money lent, or reasonable and proper rent for premises demised to the Association. Provided that this provision shall not apply to any payment to any railway, gas, electric lighting, water, cable, or telephone company of which a member of the Council or governing body may be a member, or any other company in which such member shall not hold more than one-hundredth part of the capital, and such member shall not be bound to account for any share of profits he may receive in respect of such payment.

5. The fourth paragraph of this Memorandum is a condition on which a license is granted by the Board of Trade to the Association in pursuance of Section 20 of the Companies (Consolidation) Act, 1908.

6. The liability of the members is limited.

7. Every member of the Association undertakes to contribute to the assets of the Association in the event of the same being wound up during the time that he is a member, or within one year afterwards, for payment of the debts and liabilities of the Association contracted before the time at which he ceases to be a member, and of the costs, charges, and expenses of winding up the same, and for the adjustment of the rights of the contributories amongst themselves, such amount as may be required not exceeding one pound.

8. If upon the winding-up or dissolution of the Association there remains, after satisfaction of all its debts and liabilities, any property whatsoever, the same shall not be paid to or distributed among the members of the Association, but shall be given or transferred to some other Institution or Institutions not formed or carrying on business for profit having objects similar to the objects of the Association, to be determined by the members of the Association at or before the time of dissolution, or in default thereof by such Judge of the High Court of Justice as may have or acquire jurisdiction in the matter, and if and so far as effect cannot

be given to the aforesaid provision, then to some charitable objects.

9. True accounts shall be kept of the sums of money received and expended by the Association, and the matter in respect of which such receipt and expenditure takes place, and of the property, credits, and liabilities of the Association, and, subject to any reasonable restrictions as to the time and manner of inspecting the same that may be imposed in accordance with the regulations of the Association for the time being, shall be open to the inspection of the members. Once at least in every year the accounts of the Association shall be examined and the correctness of the balance-sheet ascertained by one or more properly qualified auditor or auditors.

WE, the several persons whose names and addresses are subscribed, are desirous of being formed into an Association in pursuance of this Memorandum of Association.

NAMES, ADDRESSES, AND DESCRIPTIONS OF SUBSCRIBERS

GERARD ALBERT MUNTZ, French Walls, Birmingham, Baronet.

THOMAS TURNER, The University of Birmingham, Professor of Metallurgy.

ALFRED KIRBY HUNTINGTON, The University of London, Professor of Metallurgy.

WILLIAM H. JOHNSON, 24 Lever Street, Manchester, Iron Merchant and Manufacturer.

JAMES TAYLER MILTON, Lloyd's Register, E.C., Chief Engineer Surveyor.

ROBERT KAYE GRAY, Abbey Wood, Kent, Civil Engineer.

EMMANUEL RISTORI, 54 Parliament Street, London, S.W., Civil Engineer.

CECIL HENRY WILSON, Pitsmoor Road, Sheffield, Gold and Silver Refiner.

WILLIAM HENRY WHITE, 8 Victoria Street, Westminster, Naval Architect.

HENRY JOHN ORAM, Admiralty, London, S.W., Engineer Vice-Admiral.

Dated this 27th Day of July 1910.

Witness to the above signatures—

ARTHUR E. BURTON, Solicitor,
Hastings House, Norfolk Street,
Strand, W.C.

The Companies (Consolidation) Act, 1908

Articles of Association
OF
THE INSTITUTE OF METALS

SECTION I.—CONSTITUTION

1. For the purposes of registration the number of members of the Association is to be taken to be 1000, but the Council may from time to time register an increase of members.

2. The subscribers to the Memorandum of Association and such other members as shall be admitted in accordance with these Articles, and none others, shall be members of the Association and shall be entered on the register of members accordingly.

3. Every person who was a member of the unincorporated Society known as the Institute of Metals on the day preceding the date of the incorporation of this Association, and who has not already become a member of this Association by virtue of having subscribed the Memorandum of Association thereof, shall be entitled to be admitted to membership of the Association upon writing his name in a book which has been provided for that purpose, or upon notifying in writing to the Association at its Registered Office his desire to become a member, and immediately upon the making of such entry or the receipt of such notice, shall be deemed to have been admitted and to have become a member of the Association and shall be placed upon the register of members accordingly, and thereupon any sums due and owing by such persons to the unincorporated Society shall immediately become due and payable by him to the Association.

4. Members of the Association shall be either Honorary Members, Fellows, Ordinary Members, or Student Members, and shall be respectively entitled to use the following abbreviated distinctive titles: Hon. Members, Hon. M.Inst.Met.; Fellows, F.Inst.Met.; Ordinary Members, M.Inst.Met.; and Students, S.Inst.Met.

5. *Honorary Members*.—It shall be within the province of the Council to elect not more than twelve honorary members, who shall be persons of distinction interested in or connected with the objects of the Association. Honorary Members shall not be eligible for election on the Council nor entitled to vote at meetings of the Association, and the provisions of Article 7 and Clause 7 of the Memorandum of Association shall not apply to such members.

Fellows shall be chosen by the Council, shall be limited in number to twelve, and shall be members of the Institute who have, in the opinion of the Council, rendered eminent service to the Association.

Ordinary Members shall be more than twenty-three years of age, and shall be persons occupying responsible positions. They shall be either (a) persons engaged in the manufacture, working, or use of non-ferrous metals and alloys; or (b) persons of scientific, technical, or literary attainments connected with or interested in the metal trades or with the application of non-ferrous metals and alloys.

Student Members shall be more than seventeen years of age, and shall not remain Student Members of the Association after they are twenty-five years of age, and shall be either (a) Students of Metallurgy; or (b) pupils or assistants of persons qualified for ordinary membership whether such persons are actually members of the Association or not. Student Members shall not be eligible for election on the Council nor entitled to vote at the meetings of the Association.

SECTION II.—ELECTION OF MEMBERS.

6. Save as hereinbefore provided, applications for membership shall be in writing in the form following marked "A,"

and such application must be signed by the applicant and not less than three members of the Association.

FORM A.

To the Secretary.

I, the undersigned, _____, being of the required age and desirous of becoming a _____ Member of the Institute of Metals, agree that I will be governed by the regulations of the Association as they are now formed, or as they may be hereafter altered, and that I will advance the interests of the Association as far as may be in my power; and we, the undersigned, from our personal knowledge, do hereby recommend him for election.

Name in full.....

Address.....

Business or Profession.....

Qualifications.....

Signature.....

Dated this _____ day of _____, 19 ____.

.....	} Signatures of three Members.
.....	
.....	

7. Such applications for membership as Ordinary Members or Student Members as are approved by the Council shall be inserted in voting lists. These voting lists will constitute the ballot papers, and will specify the name, occupation, address, and proposers of each candidate. They shall be forwarded to the members for return to the Secretary at a fixed date, and four-fifths of the votes recorded shall be necessary for the election of any person.

Every such election shall be subject to the payment by the applicant of his entrance fee and first annual subscription, and he shall not become a member of the Association nor be entered on the Register of Members until such sums are actually received from him. In the event of his failing to pay such sums within the time specified in the notification to

11. Clauses 87, 89, 91, 92, 93, and 94 of the Table A in the First Schedule of the Companies (Consolidation) Act, 1908, shall apply to and form part of the Regulations of the Association, with the substitution of "Members of the Council" for "Directors" wherever in such clauses occurring.

12. The quorum for the transaction of business by the Council may be fixed by the Council, but shall not be less than five.

13. The first business of the Association shall be to acquire the property and assets, and to undertake the liabilities and obligations of the unincorporated Society known as the Institute of Metals, and for the purpose of so doing the Council shall forthwith take into consideration, and, if approved, adopt on behalf of the Association, the Agreement referred to in Clause 3 (a) of the Memorandum of Association.

14. The President shall be elected annually, and shall be eligible for re-election at the end of the first year, but shall not be eligible for re-election again until after an interval of at least two years.

15. Two Vice-Presidents and five Members of the Council, in rotation, shall retire annually, but shall be eligible for re-election. The members of the Council to retire in every year shall be those who have been longest in office since their last election, but as between persons who became members of the Council on the same day, those to retire shall (unless they otherwise agree among themselves) be determined by lot. In addition, those Vice-Presidents and Members of Council shall retire who have not attended any meeting of the Council or Association during the previous year, unless such non-attendance has been caused by special circumstances which shall have been duly notified to, and accepted by, the Council as sufficient explanation of absence.

16. At the Ordinary General Meeting preceding the Annual Meeting, the Council shall present a list of members nominated by them for election on the Council. Any ten members may also, at such Meeting, nominate a candidate other

than one of those nominated by the Council. A list of candidates so nominated shall be forwarded to each member of the Association, and must be returned by him to be received by the Secretary not later than seven days preceding the Annual Meeting.

17. A member may erase any name or names from the list so forwarded, but the number of names on the list, after such erasure, must not exceed the number to be elected to the respective offices as before enumerated. The lists which do not accord with these directions shall be rejected by the Scrutineers. The votes recorded for any member as President, shall, if he be not elected as such, count for him as Vice-President, and, if not elected as Vice-President, shall count for him as ordinary member of the Council. And the votes recorded for any member as Vice-President shall, if he be not elected as such, count for him as ordinary member of the Council.

18. The Council shall have power to appoint a member to fill up any vacancy that may occur in the Council during their year of office, but any person so appointed shall hold office only until the next following Ordinary General Meeting, and shall then be eligible for re-election.

SECTION IV.—DUTIES OF OFFICERS

19. The President shall be Chairman at all Meetings at which he shall be present, and in his absence one of the Vice-Presidents, to be elected, in case there shall be more than one present, by the Meeting. In the absence of a Vice-President, the members shall elect a Chairman for that Meeting.

20. An account shall be opened in the name of the Association with a Bank approved by the Council, into which all moneys belonging to or received by the Association shall be paid. All cheques on such account shall be signed by a member of the Council and countersigned by the Honorary

Treasurer. No account shall be paid before it has been certified as correct by the Council.

21. The Hon. Secretary or Secretaries shall be elected or appointed by the Council. He or they shall attend all Meetings, shall take minutes of the proceedings, shall be responsible for the safe custody of all papers, books, and other moveable property of the Association, and shall perform such other duties as may be prescribed by the Council from time to time. In particular, he or they shall be responsible for editing the *Journal of the Institute of Metals*.

The Council shall have power to appoint a paid Secretary or Secretaries, and to delegate to him or them all or any of the duties of the Hon. Secretary or Secretaries.

SECTION V.—GENERAL MEETINGS

22. The First General Meeting shall be held at such time, not being more than three months after the incorporation of the Association, and at such place as the Association may determine. Subsequent there shall be at least two General Meetings in each calendar year, one of which shall be held in London during the first three months of the calendar year, and the other at such time after the said Meeting to be held in London and in such locality as the Council may direct. The Meeting in London shall be the Annual General Meeting.

The quorum for a General Meeting shall be 10 members personally present.

23. The Council may convene an Extraordinary General Meeting for any special purpose whenever they consider it to be necessary. The Council shall convene an Extraordinary General Meeting for a special purpose, upon a requisition to that effect, signed by not less than twenty members. The business of such a Meeting shall be confined to the special subjects named in the notice convening the same. No member whose subscription is in arrear shall be entitled to debate or to vote at any General Meeting.

In case of equality of voting at any Meeting the Chairman shall have an additional or casting vote.

24. Seven days' notice at the least (exclusive of the day on which the notice is served or deemed to be served, but inclusive of the day for which notice is given) specifying the place, the day, and the hour of Meeting, and, in case of special business, the general nature of that business, shall be given in manner hereinafter mentioned, or in such other manner, if any, as may be prescribed by the members of the Association in General Meeting, to such persons as are, under the regulations of the Association, entitled to receive such notices from the Association, but the non-receipt of the notice by any member shall not invalidate the meeting.

25. A notice may be given by the Association to any member, either personally or by sending it by post to him to his registered address, or (if he has no registered address in the United Kingdom) to the address, if any, within the United Kingdom supplied by him to the Association for the giving of notices to him.

Where a notice is sent by post, service of the notice shall be deemed to be effected by properly addressing, prepaying, and posting a letter containing the notice, and a certificate of the Secretary or other Officer of the Association that such notice was so posted shall be sufficient proof of service. A notice so posted shall be deemed to have been served the day following that upon which it was posted.

26. If a member has no registered address in the United Kingdom, and has not supplied to the Association an address within the United Kingdom for the giving of notices to him, a notice addressed to him and advertised in a newspaper circulating in the neighbourhood of the registered office of the Association shall be deemed to be duly given to him on the day on which the advertisement appears.

27. Notice of every General Meeting shall be given in some manner hereinbefore authorised to every member of the Association, except those members who (having no registered

address within the United Kingdom) have not supplied to the Association an address within the United Kingdom for the giving of notices to them. No other persons shall be entitled to receive notices of General Meetings, but the Association may, but shall not be bound to give notice of General Meetings to members not entitled thereto in such manner as in the opinion of the Council may be practicable and convenient.

SECTION VI.—SUBSCRIPTIONS

28. The subscription of each ordinary member shall be two guineas per annum, and of each student member one guinea per annum. Ordinary members shall pay an entrance fee of two guineas each, and students an entrance fee of one guinea each. Provided that no entrance fee shall be required from any person who was a member of the unincorporated Society known as the Institute of Metals on the day preceding the Incorporation of this Association, and who had paid an entrance fee to the said Society. No entrance fee or subscription shall be payable in the case of Honorary members.

29. Subscriptions shall be payable in advance on July 1st in each year, save in the case of Ordinary Members and Student Members elected under Clauses 6 and 7 hereof, whose entrance fee and annual subscription shall become payable in accordance with the notification to them of their election. Every subscription shall cover the period down to the 30th of June next following, and no longer, and for this purpose any subscription paid to the unincorporated Society for the period of July 1st, 1909, to June 30th, 1910, by any person who becomes a member of this Association shall go and be in satisfaction of any payment due in respect of membership of this Association up to the 30th of June 1910.

30. Subject to the provisions of Clause 7 hereof, any member whose subscription shall be six months in arrear, shall forfeit temporarily all the privileges of the Association. Due notice in the Form following marked "C" shall be given to such member, and if such subscription remains

unpaid upon the date specified for payment in this notice, the Council may remove such member from the Register of Members of the Association, and thereupon any member whose name is so removed shall cease to be a member thereof, but shall nevertheless remain liable to the Association for such arrears.

FORM C.

SIR,—I am directed to inform you that your subscription to the Institute of Metals, due _____, and amounting to £ _____, is in arrear, and that if the same be not paid to me on or before the _____ day of _____, 19____, your name will be removed from the Register of Members of the Association.

I am, Sir, your obedient Servant,

.....Secretary.

31. The Council may, in their discretion, and upon such terms as they think fit (including the payment of all arrears), accede to any application for reinstatement by a person whose name has been removed from the Register under the last preceding Clause hereof, and the name of any person so reinstated shall be placed upon the Register of Members accordingly.

The Council, in their discretion, may remove from the Register the name of any member who shall, in the opinion of the Council, be undesirable or unfit to remain a member after first giving him a reasonable opportunity of being heard, and thereupon he shall cease to be a member of the Association.

SECTION VII.—AUDIT

32. The provisions of the Companies (Consolidation) Act, 1908, as to Audit and Auditors shall apply to and be observed by the Association, the first General Meeting being treated as the Statutory Meeting, the Council being treated as the Directors, and the members being treated as the Shareholders mentioned in that Act.

SECTION VIII.—JOURNAL

33. The Journal of the Association may include one or more of the following:—

- (a) Communications made by members, students, or others.
- (b) Abstracts of papers appearing elsewhere.
- (c) Original papers appearing elsewhere.
- (d) Advertisements approved by the Council.

Every member shall be entitled to receive one copy of each issue of the Journal, delivered, post free, to his registered address.

SECTION IX.—COMMUNICATIONS

34. All communications shall be submitted to the Council, and those approved may be brought before the General Meetings. This approval by the Council shall not be taken as expressing an opinion on the statements made or the arguments used in such communications.

SECTION X.—PROPERTY OF THE ASSOCIATION

35. All communications so made shall be the property of the Association, and shall be published only in the Journal of the Association, or in such other manner as the Council may decide.

36. All books, drawings, communications, models, and the like shall be accessible to members of the Association, and the Council shall have power to deposit the same in such place or places as they may consider convenient for the members.

SECTION XI.—CONSULTING OFFICERS

37. The Council shall have power to appoint such consulting officers as may be thought desirable from time to time, and, subject to the provisions of Clause 4 of the Memorandum of Association, may vote them suitable remuneration.

SECTION XII.—INDEMNITY

38. Every member of Council, Secretary, or other officer or servant of the Association, shall be indemnified by the Association against, and it shall be the duty of the Council out of the funds of the Association to pay all costs, losses, and expenses which any such officer or servant may incur or become liable to by reason of any contract entered into or act or thing done by him as such officer or servant or in any way in the discharge of his duties, including travelling expenses.

NAMES, ADDRESSES, AND DESCRIPTIONS OF SUBSCRIBERS

GERARD ALBERT MUNTZ, French Walls, Birmingham, Baronet.

THOMAS TURNER, The University of Birmingham, Professor of Metallurgy.

ALFRED KIRBY HUNTINGTON, The University of London, Professor of Metallurgy.

WILLIAM H. JOHNSON, 24 Lever Street, Manchester, Iron Merchant and Manufacturer.

JAMES TAYLER MILTON, Lloyd's Register, &c., Chief Engineer Surveyor.

ROBERT KAYE GRAY, Abbey Wood, Kent, Civil Engineer.

EMMANUEL RISTORI, 54 Parliament Street, London, S.W., Civil Engineer.

CECIL HENRY WILSON, Pitsmoor Road, Sheffield, Gold and Silver Refiner.

WILLIAM HENRY WHITE, 8 Victoria Street, Westminster, Naval Architect.

HENRY JOHN ORAM, Admiralty, London, S.W., Engineer Vice-Admiral.

Dated this 27th day of July 1910.

Witness to the above signatures—

ARTHUR E. BURTON, Solicitor,

Hastings House, Norfolk Street,

Strand, W.C.

LIST OF MEMBERS

Members of Council are indicated by italics.

Original Members are those who were elected 1908-9.

† *Denotes Contributor of Paper.*

Elected
Member.

HONORARY MEMBERS

- | | |
|------|---|
| 1910 | GLAZEBROOK, RICHARD TETLEY, C.B., M.A., D.Sc., F.R.S.,
Director, The National Physical Laboratory, Ted-
dington, Middlesex. |
| 1912 | LE CHATELIER, Professor HENRY,
75 Rue Notre Dame des Champs, Paris, France. |
| 1910 | NOBLE, Captain Sir ANDREW, Bart., K.C.B., D.L., D.C.L.,
Sc.D., F.R.S.,
14 Pall Mall, S.W. |

ORDINARY MEMBERS

- | | |
|--------|--|
| 1911 | ABBOTT, ROBERT ROWELL, B.Sc.
Peerless Motor Car Co., Cleveland, O., U.S.A. |
| 1908-9 | ADAMS, GEORGE,
Strathblane, Forest Glade, Leytonstone, Essex. |
| 1908-9 | ADAMSON, JOSEPH,
Oaklands, Hyde, Cheshire. |
| 1908-9 | AINSWORTH, GEORGE,
The Hall, Consett, Durham. |
| 1910 | ALLAN, ANDREW, Jun.,
A. Allan & Son, 486 Greenwich Street, New
York, U.S.A. |
| 1908-9 | ALLAN, JAMES McNEAL,
R. W. Hawthorn, Leslie & Co., Ltd., St. Peter's
Works, Newcastle-on-Tyne. |
| 1908-9 | ALLELY, WILLIAM SMITH,
3 Regent Street, Birmingham. |
| 1908-9 | ALLEN, JOHN HILL,
54 Westfield Road, Edgbaston, Birmingham. |

Elected Member.	
1912	ALLEN, THOMAS JAMES WIGLEY, German Silver Works, Spring Hill, Birmingham.
1908-9	ALLEN, WILLIAM HENRY, Queen's Engineering Works, Bedford.
1911	ANDERSON, FREDERIC ALFRED, B.Sc., Bank Chambers, 24 Grainger Street West, New- castle-on-Tyne.
1908-9	† ANDREW, JOHN HAROLD, M.Sc., Victoria University, Manchester.
1910	ANDRI, ALFRED, General Manager, Fabrique Nationale d'Armes de Guerre, Herstal-près-Liége, Belgium.
1908-9	APPLETON, JOSEPH, Appleton & Howard, 12 Salisbury Street, St. Helens.
1911	APPLEYARD, ROLLO, 79 St. Mary's Mansions, Paddington, W.
1908-9	ARCHBUTT, LEONARD, 4 Madeley Street, Derby.
1910	ASH, Engineer-Commander HAROLD EDWARD HAYDON, R.N., London and Glasgow Engineering Company, 172 Lancefield Street, Glasgow.
1912	ASH, PERCY CLAUDE MATCHWICK, 10 Broad Street, Golden Square, W.
1908-9	ASHOFF, WILHELM, Basse and Selve, Altena, Westphalia, Germany.
1908-9	ASTON, HENRY HOLLIS, Tennal House, Harborne, Birmingham.
1908-9	† BAILEY, GEORGE HERBERT, D.Sc., Ph.D., Edenmor, Kinlochleven, Argyll, N.B.
1908-9	BAIN, JAMES, The Cunard Engine Works, Huskisson Docks, Liverpool.
1908-9	BAINBRIDGE, JOHN WILLIAM, 2 Fen Court, Fenchurch Street, E.C.
1908-9	BAKER, THOMAS, D.Sc., M.Met., Westville, Doncaster Road, Rotherham.
1908-9	BAMFORD, CHARLES CLIFFORD, Winfields Rolling Mills, Cambridge Street, Bir- mingham.
1908-9	† BANNISTER, CHARLES OLDEN, Assoc.R.S.M., 60 West Side, Clapham Common, S.W.
1910	BARCLAY, ALEXANDER CLARK, Minas Sotiel Coronada, Prov. de Huelva, Spain.

Elected Member.		
1908-9	†	BARCLAY, WILLIAM ROBB, 50 Upper Albert Road, Meersbrook, Sheffield.
1908-9		BARKER, JOHN HENRY, Birmingham Metal and Munitions Company, Ltd., Adderley Park Mills, Birmingham.
1908-9		BARNARD, ALFRED HENRY, H. B. Barnard & Sons, 148½ Fenchurch St., E.C.
1908-9		BARNARD, GEORGE, Callendar's Cable and Construction Company, Ltd., Cambridge Street, Birmingham.
1908-9		<i>BARR, Professor ARCHIBALD, D.Sc., Westerton, Milngavie, N.B.</i>
1908-9		BARWELL, CHARLES H., Barwells Ltd., Pickford Street, Birmingham.
1910		BASSETT, WILLIAM H., American Brass Co., Waterbury, Conn., U.S.A.
1908-9		BATES, Major DARWIN, The Orchard, Huyton, Liverpool.
1908-9		BATY, ERNEST JOCELYN, B.Sc., 4 Highfield Road, Luton, Bedfordshire.
1908-9		BAWDEN, FREDERICK, Garston Copper Works, Liverpool.
1908-9		BAYLAY, WILLOUGHBY LAKE, Foremark, Dorridge, Warwickshire.
1908-9		<i>BAYLISS, THOMAS ABRAHAM, King's Norton Metal Co., Ltd., King's Norton, Bir- mingham.</i>
1908-9		BAYLISS, THOMAS RICHARD, Belmont, Northfield, Birmingham.
1908-9		BEAN, G., Allen Everitt & Sons, Ltd., Kingston Metal Works, Smethwick, Birmingham.
1908-9		BEARE, Professor T. HUDSON, B.A., B.Sc., Engineering Laboratories, The University, Edinburgh.
1908-9		BECKER, PITT, 18/19 Fenchurch Street, E.C.
1908-9		BEDFORD, CHARLES YVONE RILAND, H. H. Vivian & Co., Ltd., Icknield Port Road, Birmingham.
1908-9		BEDSON, JOSEPH PHILLIPS, 137 Lapwing Lane, Didsbury, Manchester.
1908-9		BEER, LUDWIG, Beer, Sondheimer & Co., Frankfurt-am-Main, Germany.
1910	†	<i>BEILBY, GEORGE THOMAS, LL.D., F.R.S., 11 University Gardens, Glasgow.</i>

Elected Member.	
1912	BELAIEW, Captain NICHOLAS T., Chemical Laboratory, Michael Artillery Academy, St. Petersburg, Russia.
1908-9	BELL, Sir HUGH, Bart., D.L., D.C.L., LL.D., Rounton Grange, Northallerton.
1908-9	BELL, THOMAS, J. Brown & Co., Ltd., Clydebank, Dumbartonshire.
1911	† BENEDICKS, Professor CARL ASEL FREDRIK, Ph.D., Tegnérslunden 3 ^{iv} , Stockholm Va, Sweden.
1908-9	† BENGOUGH, GUY DUNSTAN, M.A., D.Sc., The University, Liverpool.
1908-9	BENSEL, ARLINGTON, 1141 Broad Street, Newark, New Jersey, U.S.A.
1908-9	BENTON, ARTHUR, Benton Brothers, Rodley Foundry, Sheffield.
1908-9	BEVIS, HENRY, Pirelli, Limited, 144 Queen Victoria Street, E.C.
1910	BEVIS, RESTAL RATSEY, Hamptoune, Vyner Road, Birkenhead.
1908-9	BIBBY, JOHN HARTLEY, John Bibby & Company (Garston), Limited, Garston Copper Works, Liverpool.
1908-9	BILES, Professor Sir JOHN HARVARD, Kt., LL.D., D.Sc., 10 University Gardens, Glasgow.
1908-9	BILL-GOZZARD, GEORGE, Stephenson Chambers, 39A New Street, Birmingham.
1908-9	BILLINGTON, CHARLES, "Heimath," Longport, Staffordshire.
1908-9	BIRCH, HARRY, "Inglewood," Chester Road, Streetly, Birmingham.
1908-9	BLAIKLEY, ARTHUR, 10 Provost Road, South Hampstead, N.W.
1908-9	BLOOMER, FREDERICK JOHN, Penpont, Clydach, S.O., Glamorganshire.
1908-9	BLOUNT, BERTRAM, 76/78 York Street, Westminster, S.W.
1908-9	BOEDDICKER, GUSTAV ADOLF (<i>Vice-President</i>), <i>Henry Wiggin & Company, Limited, Wiggin Street Works, Birmingham.</i>
1912	BOLTON, EDWARD JOHN, Lightoaks, Oakamoor, Stoke-on-Trent.
1908-9	BOLTON, THOMAS, T. Bolton & Sons, Limited., 57 Bishopsgate, E.C.
1912	BOOTE, EDGAR MIDDLETON, 2 Lithos Road, Hampstead, N.W.
1908-9	BOOTH, CUTHBERT RAYNER, Jas. Booth & Co., Ltd., Sheepcote St., Birmingham.

Elected Member.	
1913	BORCHERS, Professor WILHELM, Dr.Ing., Dr.Ph., Ludwigsallee 15, Aachen, Germany.
1911	BOWRAN, ROBERT, Robert Bowran & Company, Limited, 4 St. Nicholas' Buildings, Newcastle-on-Tyne.
1911	BOYLSTON, HERBERT MELVILLE, B.Sc., M.A., Sauveur & Boylston, Abbot Building, Harvard Square, Cambridge, Mass., U.S.A.
1908-9	BRABY, CYRUS, F. Braby & Co., Ltd., 110 Cannon Street, E.C.
1912	BRADLEY, BENJAMIN, Bradley Ore Treatment Company (1910). Limited, Dunston Metal Works, Dunston-on-Tyne.
1908-9	BRAY, DAVID, Glenwood, Hardwick Road, Streetly, Birmingham.
1908-9	BRECKNELL, HENRY EDWIN FRANK, 330 Fishponds Road, Eastville, Bristol.
1912	BREGOWSKY, IVAN M., Crane Company, 1214 Canal Street, Chicago, Ill., U.S.A.
1908-9	BRIDGES, FREDERICK WILLIAM, <i>Hardwareman and Ironmongers' Chronicle</i> , 124 Holborn, E.C.
1908-9	BROADFOOT, JAMES, Lymhurst, South Brae Drive, Glasgow.
1908-9	BROADFOOT, WILLIAM RITCHIE, John Broadfoot & Sons, Ltd., Inchholm Works, James Street, Whiteinch, Glasgow.
1908-9	BROCKBANK, JOHN GEORGE, 1 Cannon Street, Birmingham.
1910	BROOK, GEORGE BERNARD, Cravenhurst, Fulwood, Sheffield.
1908-9	BROOKS, JOHN FREDERICK, Engineering Department, Municipal Technical School, Leicester.
1908-9	BROWN, CHARLES A. J., "Glenroy," Gillott Road, Edgbaston, Birmingham.
1910	BROWN, JAMES, Scotts' Shipbuilding and Engineering Company, Limited, Greenock.
1908-9	BROWN, ROBERT JOHN, W. Turner & Company, 75-79 Eyre Street, Sheffield.
1908-9	BROWN, WILLIAM, London Works, Renfrew.
1911	BROWN, WILLIAM MEIKLE, 46 Bede Burn Road, Jarrow-on-Tyne.

Elected Member.	
1911	BROWNE, Sir BENJAMIN CHAPMAN, Kt., Westacres, Newcastle-on-Tyne.
1908-9	BROWNSDON, HENRY WINDER, M.Sc., Ph.D., 109 Oxford Road, Moseley, Birmingham.
1908-9	BUCHANAN, CHARLES, Lloyd's Register of British and Foreign Shipping, 71 Fenchurch Street, E.C.
1908-9	BUCKWELL, GEORGE WILLIAM, Board of Trade Surveyors' Office, 73 Robertson Street, Glasgow.
1911	BUELL, WILLIAM HEANEY, Ph.B., Winchester Repeating Arms Company, New Haven, Conn., U.S.A.
1908-9	BULLEID, Professor CHARLES HENRY, M.A., University College, Nottingham.
1912	BURNER, ALFRED, A. G. Mumford, Limited, Culver Street Engineering Works, Colchester.
1908-9	BUTTENSCHAW, GEORGE ESKHOLME, "Lynbrook," Wilbraham Road, Chorlton-cum- Hardy, Lancashire.
1908-9	BUTTERFIELD, JOHN COPE, 79 Endlesham Road, Balham, S.W.
1908-9	CAIRD, PATRICK TENNANT, Belleaire, Greenock, Renfrewshire.
1908-9	CAIRD, ROBERT, LL.D., 56 Esplanade, Greenock, Renfrewshire.
1910	CAMPION, Professor ALFRED, The Royal Technical College, Glasgow.
1908-9	CANNING, THOMAS RICHARD, W. Canning & Co., 133. Great Hampton Street, Birmingham.
1911	CAPP, JOHN A., General Electric Company, Schenectady, N.Y., U.S.A.
1912	CARDOZO, HENRI ALEXANDRE, 54 Rue de Prony, Paris, France.
1908-9	CAREAGA, CIPRIANO R., Plaza Circular 4, Bilbao, Spain.
1910	CARELS, GARSTON LOUIS, 53 Dock, Ghent, Belgium.
1910	CARLYLE, Professor WILLIAM ARTHUR, B.A.Sc., Ma.E., Grange Cottage, The Grange, Wimbledon, Surrey.
1908-9	CARNT, EDWIN CHARLES, Westwood, Wootton Bridge, Isle of Wight.

Elected Member.	
1908-9	† <i>CARPENTER, Professor HENRY CORT HAROLD, M.A. (Oxon.), Ph.D. (Leipzig), (Vice-President), The University, Manchester.</i>
1908-9	<i>CARR, JAMES JOHN WILLIAM, Stoney Dale, Smethwick, Birmingham.</i>
1908-9	<i>CARTER, ARTHUR, Brookfield Villa, Stalybridge.</i>
1908-9	<i>CHALAS, EMILE CLAVEY, Chalas & Sons, Finsbury Pavement House, Fins- bury Pavement, E.C.</i>
1908-9	<i>CHAMBERS, DAVID MACDONALD, D. M. Chambers & Company, 2 Piazza Belgiojoso, Milano, Italy.</i>
1909	<i>CHARLETON, ARTHUR GEORGE, Assoc.R.S.M., 5 Avonmore Road, West Kensington, W.</i>
1911	<i>CHARPY, GEORGES, Directeur des Usines St. Jacques, Montluçon, France.</i>
1910	<i>CHATTERTON, ALFRED, B.Sc., Director of Industries, Post Box No. 112, Madras, India.</i>
1908-9	<i>CLAMER, GUILLIAM H., B.S., The Ajax Metal Company, Frankford Avenue, Philadelphia, Pa., U.S.A.</i>
1908-9	<i>CLARK, GEORGE, Richardsons, Westgarth & Company, Limited, Hartlepool.</i>
1908-9	<i>CLARK, HENRY, George Clark, Limited, Southwick Engine Works, Sunderland.</i>
1908-9	<i>CLARK, JOHN, British India Steam Navigation Company, Limited, 9 Throgmorton Avenue, E.C.</i>
1908-9	<i>CLAYTON, GEORGE CHRISTOPHER, Ph.D., Croughton, near Chester.</i>
1908-9	<i>CLEGHORN, ALEXANDER, 14 Hatfield Drive, Kelvinside, Glasgow.</i>
1908-9	<i>CLELAND, WILLIAM, B.Sc., Sheffield Testing Works, Blonk Street, Sheffield.</i>
1908-9	<i>COLLIE, CHARLES ALEXANDER, Earle, Bourne & Company, Limited, Lejonca, Bilbao, Spain.</i>
1909	<i>CONNOLLY, JAMES, Zuurfontein Foundry, Zuurfontein, Transvaal, South Africa.</i>
1908-9	<i>CONSTANTINE, EZEKIEL GRAYSON, 58 Victoria Street, Westminster, S.W.</i>

Elected Member.	
1908-9	<i>COOKSON, CLIVE,</i> <i>Cookson & Company, Limited, Milburn House,</i> <i>Newcastle-on-Tyne.</i>
1908-9	<i>CORFIELD, JOHN,</i> <i>Dillwyn & Company, Limited, Swansea.</i>
1908-9	<i>CORFIELD, REGINALD WILLIAM GODFREY, Assoc.R.S.M.,</i> <i>5 Richmond Villas, Swansea.</i>
1908-9	<i>CORSE, WILLIAM MALCOLM, B.Sc.,</i> <i>Secretary, American Institute of Metals, c/o Lumen</i> <i>Bearing Company, Buffalo, N.Y., U.S.A.</i>
1908-9	<i>COURTMAN, ERNEST OWEN, Assoc.R.S.M.,</i> <i>Denford House, Atkins Road, Clapham Park, S.W.</i>
1912	<i>COWAN, GEORGE DUNFORD,</i> <i>Bridge House, Bridge Road, Millwall, E.</i>
1908-9	<i>COWPER-COLES, SHERARD OSBORN,</i> <i>The Cottage, French Street, Sunbury-on-Thames.</i>
1910	<i>CRAWFORD, WILLIAM MITCHELL,</i> <i>41 Kelvinside Gardens N., Glasgow.</i>
1908-9	<i>CRIGHTON, ROBERT,</i> <i>Harland & Wolff, Limited, Bootle, Liverpool.</i>
1911	<i>CROFTS, FREDERICK J.,</i> <i>Bloomfield House, Tipton.</i>
1908-9	<i>CROSLAND, JAMES FOYELL LOVELOCK,</i> <i>67 King Street, Manchester.</i>
1908-9	<i>CROWTHER, JAMES GUEST,</i> <i>5 Sharrow Mount, Psalter Lane, Sheffield.</i>
1911	<i>CULLEN, WILLIAM HART,</i> <i>Castner - Kellner Alkali Company, Limited,</i> <i>Wallsend, Northumberland.</i>
1911	<i>DALE, ROBERT DAVIDSON,</i> <i>121 Colmore Row, Birmingham.</i>
1910	<i>DANCE, EDWARD LEONARD,</i> <i>20 Lovaine Place, Newcastle-on-Tyne.</i>
1908-9	<i>DANKS, AARON TURNER,</i> <i>John Danks & Son, Proprietary, Limited, 391</i> <i>Bourke Street, Melbourne, Victoria, Australia.</i>
1909	<i>DAVIES, PETER, Jun.,</i> <i>Crown Copper Works, Garston, Liverpool.</i>
1908-9	<i>DAVISON, Captain HERBERT,</i> <i>379 Upper Richmond Road, S.W.</i>
1912	<i>DAWLINGS, RICHARD MAURICE NEAVE,</i> <i>85 Teignmouth Road, Brondesbury, N.W.</i>
1910	<i>DAWSON, WILLIAM FRANCIS,</i> <i>The General Electric Company, West Lynn, Mass.,</i> <i>U.S.A.</i>

Elected Member.	
1908-9	DEER, GEORGE, Rio Tinto Company, Port Talbot, South Wales.
1908-9	DENDY, EDWARD EVERSLED, Elliott's Metal Company, Limited, Selly Oak, Birmingham.
1908-9	DENNY, JAMES, Engine Works, Dumbarton.
1908-9	† DESCH, CECIL HENRY, D.Sc. (Lond.), Ph.D. (Wurz.), Metallurgical Chemistry Laboratory, The Univer- sity, Glasgow.
1910	DESGRAZ, ADOLPHE, Prinzenstrasse 1A, Hanover, Germany.
1911	DEWRANCE, JOHN, 165 Great Dover Street, S.E.
1908-9	DINGWALL, FREDERICK WILLIAM, 40 Chapel Street, Liverpool.
1908-9	DOBBS, ERNEST WALTER, 110 Holly Road, Handsworth, Birmingham.
1908-9	DRURY, HARRY JAMES HUTCHISON, 4 Priorton Terrace, Swansea.
1908-9	DUFF, PHILIP JOHN, Apartment 4c, 548 West 164th Street, New York City, U.S.A.
1908-9	DUGARD, GEORGE HEATON, Dugard Brothers, Vulcan Mills, Birmingham.
1908-9	DUGARD, HERBERT ARTHUR, Dugard Brothers, Shadwell Street Mills, Birmingham.
1911	DUNCAN, HUGH MALCOLM, B.Sc., 5 King Edward's Road, Heaton, Newcastle-on-Tyne.
1908-9	DUNN, JOHN THOMAS, D.Sc., Public Analyst's Laboratory, 10 Dean Street, Newcastle-on-Tyne.
1911	DUNSMUIR, GEORGE AUGUSTUS, Dunsmuir & Jackson, Limited, Govan Engine Works, Govan, Glasgow.
1908-9	DYSON, WILLIAM HENRY, The Amalgams Company, Limited, Attercliffe Road, Sheffield.
1908-9	EARLE, JOHN WILLIAM, Heath Street South, Birmingham.
1908-9	ECCLES, ERNEST EDWARD, The British Aluminium Company, Ltd., Fcyers, N.B.
1908-9	† ECHEVARRI, JUAN THOMAS WOOD, 43 Merton Hall Road, Wimbledon, S.W.

Elected Member.	
1908-9	EDEN, CHARLES HAMILTON, Glynderwen, Blackpill, S.O., Glamorganshire.
1908-9	EDMISTON, JOHN ALEXANDER CLARK, 53 West Road, Irvine, Ayrshire.
1908-9	† EDWARDS, CHARLES ALFRED, M.Sc., Dorman, Long & Company, Britannia Works, Middlesbrough.
1908-9	EDWARDS, JOHN JAMES, Royal Laboratory, Royal Arsenal, Woolwich.
1908-9	ELLIS, HENRY DISNEY, 30 Blackheath Park, S.E.
1911	ELY, TALFOURD, India-rubber, Gutta-percha, and Telegraph Works Company, Limited, Silvertown, E.
1910	ENTHOVEN, HENRY JOHN, 153 Leadenhall Street, E.C.
1910	ESSLEMONT, ALFRED SHERWOOD, County of Durham Electrical Power Distribution Company, Royal Exchange Buildings, New- castle-on-Tyne.
1908-9	EVANS, SAMUEL, M.Sc., Bradley Williams Ore Treatment Company (1910), Limited, Dunston Metal Works, Dunston-on- Tyne.
1911	EVERED, STANLEY, Evered & Company, Limited, Surrey Works, Smethwick, Birmingham.
1908-9	FARLEY, DOUGLAS HENRY, Union Lane, Sheffield.
1911	FAY, HENRY, A.M., Ph.D., Mass. Institute of Technology, Boston, Mass., U.S.A.
1908-9	FÉRON, ALBERT, 49 Rue du Châtelain, Brussels, Belgium.
1911	FERRY, CHARLES, Bridgeport Brass Company, Bridgeport, Conn., U.S.A.
1908-9	FISHER, HENRY JUTSON, A. T. Becks & Company, 54 Clement Street, Birmingham.
1911	FOERSTERLING, HANS, The Roessler and Hasslacher Chemical Company, Perth Amboy, N.J., U.S.A.
1911	FORSBERG, ERIK AUGUST, Aktiebolaget Separator, Fleminggatan 8, Stock- holm, Sweden.
1910	FORSSTEDT, JAMES, Aktiebolaget Svenska Metallverken, Vesterås, Sweden.

Elected Member.	
1908-9	FRANCIS, ARTHUR AUBREY, 38 Lime Street, E.C.
1908-9	FRANCIS, REGINALD, The English Crown Spelter Company, Limited, 9 Queen Street Place, E.C.
1908-9	FRASER, KENNETH, The Yorkshire Copper Works, Limited, Pontefract Road, Leeds.
1908-9	FREY, J. HEINRICH, Zürich, Switzerland.
1908-9	GARDNER, HENRY, H. R. Merton & Company, Limited, Billiter Buildings, E.C.
1908-9	GARDNER, JAMES ALEXANDER, Ayrshire, 21 Cuthbert Place, Kilmarnock.
1908-9	GARFIELD, ALEXANDER STANLEY, B.Sc., 10 Rue de Londres, Paris, France.
1912	GARLAND, HERBERT, P.O. Box 417, Cairo, Egypt.
1908-9	GARNHAM, FREDERICK MALCOLM, 23 Durley Road, Stamford Hill, N.
1908-9	GARNHAM, JAMES COOTE, 132 Upper Thames Street, E.C.
1912	GARRETT-SMITH, NOEL, Edison & Swan United Electric Light Company, Limited, Ponder's End, Middlesex.
1908-9	GAYWOOD, CHARLES FREDERICK, Sydney Cottage, Durham Road, Sparkhill, Birmingham.
1912	GEM, EVELYN PERCY, George Johnson & Company, Montgomery Street, Sparkbrook, Birmingham.
1911	GIBB, MAURICE SYLVESTER, Central Marine Engine Works, West Hartlepool.
1908-9	GIBBINS, WILLIAM WATERHOUSE, M.A., Selly Oak, Birmingham.
1908-9	GIBBONS, WILLIAM GREGORY, (<i>Address missing.</i>)
1908-9	GILCHRIST, JAMES, Stobcross Engine Works, Glasgow.
1910	GILLETT, HORACE W., A.B., Ph.D., Morse Hall, Ithaca, New York, U.S.A.
1910	GIRDWOOD, ROBERT WALKER, Wm. Gallimore & Sons, Arundel Works, Sheffield.

Elected Member.	
1908-9	GIRTIN, THOMAS, M.A., H. L. Raphael's Refinery, 48 Thomas Street, Limehouse, E.
1908-9	GOLDSCHMIDT, HANS, Ph.D., Th. Goldschmidt Chemical and Tin Smelting Works, Essen-Ruhr, Germany.
1908-9	GOODWIN, Engineer-Rear-Admiral GEORGE GOODWIN, R.N., C.B., "Meadowside," 91 Thurleigh Road, Wandsworth Common, S.W.
1912	GORDON, JOSEPH GORDON, 15 Queen Anne's Mansions, S.W.
1908-9	GOWER, FRANCIS WILLIAM, The Birmingham Aluminium Casting (1903) Company, Limited, Cambridge Street, Birmingham.
1908-9	† GOWLAND, Professor WILLIAM, F.R.S., Assoc.R.S.M. (Past-President), 13 Russell Road, Kensington, W.
1908-9	GRACIE, ALEXANDER, Fairfield Works, Govan, Glasgow.
1912	GRAHAM, ALFRED HENRY IRVINE, Fuller's Cottage, Ditton Rd., Surbiton.
1908-9	GRAY, ROBERT KAYE, India-rubber, Gutta-percha, and Telegraph Works Company, Limited, 106 Cannon Street, E.C.
1910	GRAZEBROOK, Engineer-Lieutenant ROBERT, R.N., The Admiralty, Whitehall, Westminster, S.W.
1908-9	† GREENWOOD, HERBERT WILLIAM, "Buenos Aires," Los Barreros, Cartagena, Spain.
1908-9	GREENWOOD, THOMAS, Rosegarth, Ilkley, Yorkshire.
1910	GREENWOOD, VLADIMIR EDWARD, (Address missing.)
1908-9	GREER, HENRY HOLME AIREY, James C. Greer & Son, 62 Buchanan Street, Glasgow.
1910	GREGORY, SEWELL HARDING, 120 Coleherne Court, S.W.
1908-9	GRICE, EDWIN, 5 Beach Mansions, Southsea, Hampshire.
1908-9	GRIFFITHS, HAROLD, The New Delaville Spelter Company, Limited, Spring Hill, Birmingham.
1909	GRIMSTON, FRANCIS SYLVESTER, Hawksdale, Naini Tal, Upper India.

Elected Member.	
1912	GROVES, CLARENCE RICHARD, M.Sc., Gamble Institute, St. Helens, Lancashire.
1911	GUERTLER, WILLIAM MINOT, Ph.D., Kunz-Buntschuh-Str. 7B, Berlin-Grünwald, Germany.
1912	GUESS, Professor GEORGE A., Oakville, Ontario, Canada.
1908-9	GUILLEMIN, GEORGES, 16 Rue du Sommerard, Paris (5 ^e), France.
1908-9	GUILLET, Professor LÉON, 8 Avenue des Ternes, Paris, France.
1908-9	GULLIVER, GILBERT HENRY, B.Sc., The University, Edinburgh.
1908-9	GWYER, ALFRED GEORGE COOPER, B.Sc. (Lond.), Ph.D. (Gottt.). The British Aluminium Company, Limited, Milton, Staffordshire.
1910	HADDOCK, WALTER THORPE, The Heeley Silver-Rolling and Wire Mills, Ltd., Sheffield.
1908-9	HADFIELD, Sir ROBERT ABBOTT, Kt., D.Sc., F.R.S., D.Met., 22 Carlton House Terrace, S.W.
1908-9	HAGGIE, ROBERT HOOD, Tyne Holme, Wealdstone, Middlesex.
1908-9	HALL, HENRY PLATT, Platt Brothers and Company, Limited, Oldham.
1908-9	HALL-BROWN, EBENEZER, Richardsons, Westgarth & Co., Ltd., Middlesbrough.
1908-9	HALLETT, JOSEPH, 70 Fenchurch Street, E.C.
1908-9	HAMILTON, GERARD MONTAGUE, Calle Chicarreros 10, Sevilla, Spain.
1911	HANKINSON, ALFRED, Richard Johnson, Clapham & Morris, Limited, P.O. Box 1102, Sydney, Australia.
1911	HANNA, ROBERT WALKER, 4 Birch Terrace, Dickenson Road, Rusholme, Manchester.
1911	HANNA, WILLIAM GEORGE, 4 Birch Terrace, Dickenson Road, Rusholme, Manchester.
1908-9	HARBORD, FRANK WILLIAM, Assoc.R.S.M., 16 Victoria Street, Westminster, S.W.
1908-9	HARLOW, BERNARD SCHÄFFER, Robert Harlow & Son, Heaton Norris, Stockport.

Elected Member.		
1908-9		HARRIS, HENRY WILLIAM, 2 Fairlawn Mansions, New Cross Gate, S.E.
1911		HARRIS, THOMAS ROBERT, 2 Calverley Villas, Dawley Road, Harlington, Middlesex.
1911		HARRISON, JOHN SAMUEL, Llanberis, Chester Road, near Erdington, Birmingham.
1908-9		HARTLEY, RICHARD FREDERICK, B.Sc., Royal Laboratory, Royal Arsenal, Woolwich.
1911	†	HAUGHTON, JOHN LESLIE, M.Sc., 51 Clarence Road, Teddington, Middlesex.
1908-9		HEAP, JOHN HENRY, The British Mining and Metal Company, Limited, 123-127 Cannon Street, E.C.
1908-9		HEAP, RAY DOUGLAS THEODORE, 3 Vanbrugh Park Road West, Blackheath, S.E.
1908-9		HEATHCOTE, HENRY LEONARD, B.Sc., Rudge-Whitworth, Limited, Coventry.
1908-9		HEBERLEIN, FERDINAND, Bockenheimer Anlage 45, Frankfurt am Main, Germany.
1908-9		HECKFORD, ARTHUR EGERTON, Birmingham Metal Works, Frederick Street, Birmingham.
1910		HEINRICH, EUGEN, P. H. Muntz & Company, Limited, Alexandra Works, West Bromwich.
1911		HENDRY, Colonel PATRICK WILLIAM, Chairman, Hendry Brothers, Limited, 32 Robertson Street, Glasgow.
1908-9		HERDSMAN, WILLIAM HENRY, 22 Newlands Park, Sydenham, S.E.
1912		HEUSLER, FRIEDRICH, Ph.D., Isabellen-Hütte, Dillenburg (Hessen-Nassau), Germany.
1911		HEWITT, Professor JOHN THEODORE, M.A., D.Sc., Ph.D., F.R.S., Clifford House, Bedfont, Middlesex.
1908-9		HEYCOCK, CHARLES THOMAS, M.A., F.R.S., 3 St. Peter's Terrace, Cambridge.
1908-9		HIGHTON, DOUGLAS CLIFFORD, M.A., Highton & Son, Limited, Brassfounders and Engineers, 20 Graham Street, City Road, N.
1911		HILL, ERNEST HENRY, 13 East Grove Road, Sheffield.

Elected Member.	
1908-9	HILLS, CHARLES HAROLD, B.Sc., Heatherdown, Hindhead, Haslemere, Surrey.
1908-9	HIRST, TOM GREENOUGH, 49 Union Street, Leigh, Lancashire.
1911	HOBSON, ARTHUR E., International Silver Company, Meriden, Conn., U.S.A.
1908-9	HODGKINSON, Professor WILLIAM RICHARD E., M.A., Ph.D., 89 Shooter's Hill Road, Blackheath, S.E.
1908-9	HOFMAN, Professor HEINRICH OSCAR, Ph.D., Institute of Technology, Boston, Mass., U.S.A.
1911	HOGG, THOMAS WILLIAMS, John Spencer & Sons, Ltd., Newburn Steel Works, near Newcastle-on-Tyne.
1908-9	HOLLOWAY, GEORGE THOMAS, Assoc.R.S.M., 9-13 Emmett Street, Limehouse, E.
1908-9	HOLMES, JOSEPH, Welsh Tinplate and Metal Stamping Company, Limited, Brondeg, Llanelly, South Wales.
1908-9	HOLT, HAROLD, E. Kempster & Sons, Borough Brass Works, Bury, Lancashire.
1912	HOLT, THOMAS WILLIAM, 103 Wakefield Road, Salybridge, Manchester.
1910	HOOD, JAMES MACLAY, Rowallan, Maryland Drive, Glasgow, S.W.
1908-9	HOOTON, ARTHUR J. S., S. H. Johnson & Company, Limited, Engineering Works, Carpenter's Road, Stratford, E.
1908-9	HOPKINS, SUWARROW MOORE, Birmingham Battery and Metal Company, Ltd., Selly Oak, Birmingham.
1908-9	HOPKINSON, FRANK ADDY, Chairman, J. Hopkinson & Company, Limited, Britannia Works, Huddersfield.
1908-9	HOWE, Professor HENRY MARION, M.A., B.Sc., LL.D., Broad Brook Road, Bedford Hills, N.Y., U.S.A.
1913	HOYT, Professor SAMUEL LESLIE, School of Mines, University of Minneapolis, Minneapolis, Minn., U.S.A.
1908 9	† HUDSON, OSWALD FREEMAN, M.Sc., The University, Edgbaston, Birmingham.
1910	† HUGHES, GEORGE, <i>Lancashire and Yorkshire Railway Works, Horwich, Lancashire.</i>
1908-9	HUGHES, GEORGE FREDERICK, Box 23, Pietersburg, Transvaal, South Africa.

Elected Member.	
1908-9	HUGHES, JOSEPH, Albion Metal Works, Woodcock Street, Birmingham.
1908-9	† HUGHES, THEOPHILUS VAUGHAN, Assoc.R.S.M., 130 Edmund Street, Birmingham.
1912	HULL, DANIEL RAYMOND, American Brass Company, Kenosha, Wisconsin, U.S.A.
1908-9	HUMPHREYS, THOMAS CLEMENT, 76 Gibbins Road, Selly Oak, Birmingham.
1908-9	† HUMPHRIES, HENRY JAMES, Atlas Metal and Alloys Company, 52 Queen Victoria Street, E.C.
1908-9	HUNTER, GEORGE BURTON, D.Sc., Wallsend-on-Tyne.
1908-9	HUNTER, SUMMERS (<i>Vice-President</i>), 1 Manor Terrace, Tynemouth.
1908-9	† HUNTINGTON, Professor ALFRED KIRBY, Assoc.R.S.M. (<i>President</i>), <i>Metallurgical Laboratories, King's College, London.</i>
1908-9	HURBURGH, LEONARD HENRY, W. F. Dennis & Co., 49 Queen Victoria Street, E.C.
1908-9	HURREN, FREDERICK HAROLD, 6 Earlsdon Lane, Coventry.
1908-9	HUSSEY, ARTHUR VIVIAN, Dolgarrog Works, Tal-y-cafn, North Wales.
1908-9	HUTTON, ROBERT SALMON, D.Sc., <i>William Hutton & Sons, Limited, Sheffield.</i>
1908-9	HYMAN, WALTER, I. & J. Hyman, Thornhill Bridge Wharf, London, N.
1910	INGLIS, GEORGE ALEXANDER, B.Sc., 64 Warroch Street, Glasgow.
1910	JACK, HENRY JOSEPH, 60 London Wall, E.C.
1908-9	JACKSON, RICHARD, Burn Croft, Rosemary Hill, Little Aston, Sutton Coldfield, Birmingham.
1910	JACKSON, SYDNEY ALBERT, "Orotava," Parsonage Road, Heaton Moor, Man- chester.
1908-9	JACOB, ARTHUR, The British Aluminium Company, Limited, 109 Queen Victoria Street, E.C.
1908-9	JACOB, HENRY, Henry Jacob & Company, 9 Water Lane, E.C.

Elected Member.	
1908-9	JACOBS, HARRY, Exchange Buildings, New Street, Birmingham.
1908-9	JAGO, WILLIAM HENRY, Admiralty Overseer, 59 Vancouver Road, Forest Hill, S.E.
1912	JAMES, GARNET WILLIAMS, M.A. (Oxon.), Metallurgical Laboratory, King's College, W.C.
1911	JARRY, E. V., R. Buckland & Son, 10/11 Hop Gardens, St. Martin's Lane, W.C.
1912	JENNISON, HERBERT CHARNOCK, P.O. Box 348, Ansonia, Conn., U.S.A.
1908-9	JOHNSON, ARTHUR LAURENCE, M.A., Woodleigh, Altrincham.
1908-9	JOHNSON, BERNARD ANGAS, c/o National Provincial Bank, Finchley Road, Hampstead, N.W.
1908-9	JOHNSON, ERNEST, M.A., Richard Johnson & Nephew, Limited, Bradford Iron Works, Manchester.
1908-9	† JOHNSON, FREDERICK, M.Sc., Metallurgical Department, Municipal Technical School, Suffolk Street, Birmingham.
1908-9	JOHNSON, HAROLD MARSLAND, Bradford Iron Works, Manchester.
1908-9	JOHNSON, WILLIAM HENRY, B.Sc. (<i>Vice-President</i>), <i>Richard Johnson, Clapham & Morris, Limited,</i> <i>24 Lever Street, Manchester.</i>
1908-9	JOHNSON, WILLIAM MORTON, M.A., Richard Johnson, Clapham & Morris, Limited, 24 Lever Street, Manchester.
1908-9	JUDE, ALEXANDER ARCHIE, Belliss and Morcom, Limited, Birmingham.
1908-9	KAMPS, HANS, Directeur de la Fabrique Nationale de Tubes sans Soudre, Merxem-lez-Anvers, Belgium.
1908-9	KAYE, HARRY, H. B. Barnard & Sons, 148½ Fenchurch Street, E.C.
1908-9	KEELING, A. D., Warstone Metal Works, Hall Street, Birmingham.
1908-9	KEIFFENHEIM, ERWIN CHARLES, The Metallurgical Company, A. Keiffenheim and Sons, Milburn House, Newcastle-on-Tyne.
1908-9	KEIFFENHEIM, HUGO WILLIAM, The Metallurgical Company, A. Keiffenheim and Sons, Milburn House, Newcastle-on-Tyne.

Elected Member.	
1908-9	KEMP, JOHN FRANK, A. Kemp & Son, Tenby Street North, Birmingham.
1908-9	KENDREW, THOMAS, Broughton Copper Company, Limited, Manchester.
1910	KIDSTON, WILLIAM HAMILTON, 81 Great Clyde Street, Glasgow.
1908-9	KING, ERNEST GERALD, Editor, <i>The Metal Industry</i> , 33 Bedford Street, Strand, W.C.
1908-9	KIRKALDY, JOHN, 101 Leadenhall Street, E.C.
1913	KIRKALDY, WILLIAM GEORGE, 99 Southwark Street, S.E.
1908-9	KIRKPATRICK, VINCENT, Closeburn, Hartopp Road, Four Oaks, Sutton Coldfield, Birmingham.
1908-9	† KLEIN, CARL ADOLPHE, 4 Brimsdown Avenue, Enfield Highway, Middlesex.
1908-9	LACY, WILLIAM YAVEIR, Oak Mount, Westbourne Road, Edgbaston, Birmingham.
1908-9	LAING, ANDREW, 15 Osborne Road, Newcastle-on-Tyne.
1912	LAMBERT, ARTHUR REGINALD, Mitsui & Company, Limited, 33 Lime Street, E.C.
1913	LAMBERT, WESLEY, A. K. C., 55 Plumstead Common Road, S.E.
1908-9	LANCASTER, HARRY CHARLES, Locke, Lancaster and W. W. and R. Johnson and Sons, Limited, 94 Gracechurch Street, E.C.
1908-9	LANDSBERG, HEINRICH, Hedderheimer Kupferwerk und Süddeutsche Kabelwerke, Aktiengesellschaft, Frankfurt-am- Main, Germany.
1908-9	LANG, CHARLES RUSSELL, G. & J. Weir, Limited, Holm Foundry, Cathcart, Glasgow.
1908-9	LANGDON, PALMER H., Editor, <i>The Metal Industry</i> , 99 John Street, New York City, U.S.A.
1908-9	LANGENBACH, OSCAR, 17 Bolton Gardens, S.W.
1908-9	LANTSBERRY, FREDERICK C. A. H., M.Sc., 63 Walford Road, Sparkbrook, Birmingham.
1908-9	† LAW, EDWARD FULTON, Assoc.R.S.M., 16 Victoria Street, Westminster, S.W.
1911	LAZARUS, WILLIAM, 193 Regent Street, W.

Elected Member.	
1911	LEDOUX, ALBERT R., Ledoux & Company, 99 John Street, New York City, N.Y., U.S.A.
1908-9	LEES, CHARLES, Loanda, Wickwar, Gloucester.
1908-9	LEIGH, CECIL, Birmingham Metal and Munitions Company, Limited, Birmingham.
1908-9	LESLIE, ROBERT, P. & O. Steam Navigation Company, 122 Leadenhall Street, E.C.
1908-9	LESSNER, CHARLES BLÜTHNER, The San Finx Tin Mines, Limited, Carril, Spain.
1908-9	LESTER, WALTER, The Phosphor Bronze Company, Limited, 87 Sumner Street, S.E.
1911	LETCHER, WILLIAM WHITBURN, 84 Queen Elizabeth's Walk, Lordship Park, N.
1910	LEVI, CLIVE JOSEPH, B.Sc., 143 Newhall Street, Birmingham.
1912	LITTLE, ARTHUR DEHON, Arthur D. Little, Inc., 93 Broad Street, Boston, Mass., U.S.A.
1911	LIVERSIDGE, Engineer-Commander EDWARD WILLIAM, R.N., H.M. Dockyard, Gibraltar.
1908-9	LONGMUIR, PERCY, B.Met., Ravenscrag, Wortley, near Sheffield.
1908-9	LORD, FITZHERBERT ALBERT BUGBY, 49 Queen Victoria Street, E.C.
1910	LOUIS, Professor HENRY, M.A., D.Sc., Assoc.R.S.M., 4 Osborne Terrace, Newcastle-on-Tyne.
1910	LOW, ARCHIBALD NICOL, Partick Brass Foundry Company, Merkland Works, Partick, Glasgow.
1908-9	McCONWELL, ARTHUR, 60 Drury Buildings, Water Street, Liverpool.
1910	MACFEE, ROBERT, 15 Alexandra Grove, Chorlton-on-Medlock, Manchester.
1912	MACINTOSH, JAMES RAE, B.Sc., Siemens Brothers Dynamo Works, Limited, Central House, Birmingham.
1908-9	McKECHNIE, ALEXANDER, McKechnie Brothers, Rotton Park Street, Birmingham.
1910	McKECHNIE, JAMES, Vickers, Limited, Barrow-in-Furness.

Elected Member. 1908-9	MACKENZIE, WILLIAM, McKechie Brothers, 90 Pilgrim Street, Newcastle- on-Tyne.
1908-9	McLAURIN, Engineer-Commander JOHN, R.N., The Laurels, Branksome Wood Road, Fleet, Hampshire.
1908-9	† MCWILLIAM, Professor ANDREW, Assoc.R.S.M., D.Met., Kalimati, B. N. Railway, India.
1912	MALBY, SETH GRANT, Aluminium Company of America, 99 John Street, New York City, U.S.A.
1911	MALLISONT, GEORGE, 50 Fenchurch Street, E.C.
1911	MANTHORPE, ROBERT SALTON, Poste Restante, Brisbane, Queensland, Australia.
1908-9	MAPPLEBECK, EDWARD, Liverpool Street, Birmingham.
1908-9	MAPPLEBECK, EDWARD PERCY WILKES, J. Wilkes, Sons & Mapplebeck, Limited, Liverpool Street, Birmingham.
1912	MARSHALL, Engineer-Commander FREDERICK WILLIAM, R.N. The Admiralty, Whitehall, Westminster, S.W.
1908-9	MASON, FRANK, Wayland House, 70 Wayland Road, Sheffield.
1910	MAW, WILLIAM HENRY, LL.D., 18 Addison Road, Kensington, W.
1908-9	MAY, WILLIAM WALKER, Woodbourne, Minard Avenue, Partickhill, Glasgow.
1913	MAYO, CHARLES ROBERT, 155 Dashwood House, New Broad Street, E.C.
1908-9	MENZIES, JOHN, Merton Abbey, S.W.
1908-9	MERCER, JAMES BURY, Hollycroft, Deepthwaite, Milnthorpe, Westmorland.
1908-9	MERRETT, WILLIAM HENRY, Assoc.R.S.M., Hatherley, Grosvenor Road, Wallington, Surrey.
1908-9	MEYJES, ANTHONY CORNELIUS, Editor, <i>The Ironmonger</i> , 42 Cannon Street, E.C.
1910	MEYRICK, LEWIS JENKIN, 137 City Road, Birmingham.
1911	MICHIE, ARTHUR C., D.Sc., The Wallsend Laboratories, Neptune Road, Wallsend-on-Tyne.
1908-9	MILLER, JOHN, 52 Hillside Terrace, Springburn, Glasgow.

Elected Member.	
1908-9	MILLINGTON, ERNEST, Manor Road, Borrowash, Derby.
1908-9	MILLS, EDWARD, Williams, Foster & Company, and Pascoe, Grenfell & Sons, Limited, Morfa Copper Works, Swansea.
1912	MILLS, HARRY, Grice, Grice & Son, Limited, Nile Street, Birmingham.
1908-9	† MILLS, JOHN HODGSON, Atlas Aluminium Works, Grove Street, Birmingham.
1908-9	MILLS, WILLIAM, "Danesbury," Alderbrook Road, Solihull, Warwickshire.
1908-9	† MILTON, JAMES TAYLER, Lloyd's Register of British and Foreign Shipping, 71 Fenchurch Street, E.C.
1908-9	MITTON, THOMAS E., Hunt & Mitton, Crown Brass Works, Oozells Street North, Birmingham.
1908-9	MORCOM, EDGAR LLEWELLYN, M.A., Trencrom, Woodbourne Road, Edgbaston, Birmingham.
1910	MOREHEAD, CHARLES, 72 Highbury, West Jesmond, Newcastle-on-Tyne.
1908-9	MORISON, WILLIAM, 172 Lancefield Street, Glasgow.
1908-9	MORRISON, WILLIAM MURRAY, <i>The British Aluminium Company, Limited, 109 Queen Victoria Street, E.C.</i>
1900-9	MOUNT, EDWARD, Oaklands, Aughton, near Ormskirk, Lancashire.
1909	MÜNKER, EMIL, Merkator Str. 186, Duisburg, Germany.
1908-9	† MUNTZ, Sir GERARD ALBERT, Bart. (Past-President), <i>Muntz's Metal Company, Limited, French Walls, near Birmingham.</i>
1910	† MURRAY, MYLES THORNTON, M.Sc., South African School of Mines, Johannesburg, Transvaal, South Africa.
1908-9	MURRAY, WILLIAM, Jun., John Mills & Sons, Walker-Gate Brass Works, Newcastle-on-Tyne.
1912	NARRACOTT, RONALD WILLIAM, D.Sc., The British Mining and Metal Company, Limited, 123-125 and 127 Cannon Street, E.C.

Elected Member.	
1912	NEAD, JOHN HUNTER, B.S., c/o H. H. Franklin Manufacturing Company, Syracuse, N.Y., U.S.A.
1908-9	NESBIT, DAVID MEIN, Northumbria, Knighton Drive, Leicester.
1908-9	NIGGEMANN, BERNHARD JOSEPH, 26 Chapel Street, Liverpool.
1908-9	NISBETT, GEORGE HIND, British Insulated and Helsby Cables, Limited, Prescot, Lancashire.
1908-9	NORMAN, JOHN THOMAS, The City Central Laboratory, 23 Leadenhall Street, E.C.
1910	OAKDEN, Professor WILLIAM EDWARD, 2 Gledhow Terrace, South Kensington, S.W.
1908-9	OGG, Major GEORGE SIM, R.A., Ishapore, Bengal, India.
1912	OLSSON, MARTIN CAMPBELL, 6 St. Helen's Place, E.C.
1910	ONYON, Engineer-Captain WILLIAM, M.V.O., R.N., W. Beardmore & Co., Dalmeir, N.B.
1908-9	ORAM, <i>Engineer Vice-Admiral Sir HENRY JOHN, K.C.B., F.R.S. (Vice-President), The Admiralty, Whitehall, Westminster, S.W.</i>
1908-9	ORDE, EDWIN LANCELOT, Sir W. G. Armstrong, Whitworth & Company, Limited, Wallsend Shipyard, Newcastle-on- Tyne.
1908-9	OWEN, HALSALL, Burfield, Appleton, near Warrington.
1912	PALMER, ARTHUR CECIL HUNTER, Queensland Government Offices, 410 Strand, W.C.
1908-9	PARKER, WILLIAM BAYLEY, 1 Murray Road, Rugby.
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A
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INSTITUTE OF METALS.

Founded 1908.

Incorporated 1910.

To the Secretary,

I, the undersigned....., being of the required age and desirous of becoming aMember of the INSTITUTE OF METALS, agree that I will be governed by the regulations of the Association as they are now formed, or as they may be hereafter altered, and that I will advance the interests of the Association as far as may be in my power; and we, the undersigned, from our personal knowledge, do hereby recommend him for election.

Name in full.....

Address.....

Business or Profession.....

Qualifications.....

Signature.....

Dated this.....day of....., 191 .

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Signatures
of three
Members.

The Council, having considered the above recommendation, present Mr.....to be Balloted for as a.....Member of the INSTITUTE OF METALS.

To be filled up
by the
Council.

CAXTON HOUSE,

WESTMINSTER, S.W.,

Chairman.

Dated this.....day of.....191.....

[FOR QUALIFICATIONS OF MEMBERS, SEE SECTION 1, OTHER SIDE.]

(It would be a convenience if the Candidate's Card were sent with this form.)

EXTRACTS FROM THE RULES.

(MEMORANDUM AND ARTICLES OF ASSOCIATION.)

SECTION I.—CONSTITUTION.

Rule 4.—Members of the Association shall be either Honorary Members, Fellows, Ordinary Members, or Student Members.

Rule 5.—*Ordinary Members* shall be more than twenty-three years of age, and shall be persons occupying responsible positions. They shall be:—

either (a) persons engaged in the manufacture, working, or use of non-ferrous metals and alloys;

or (b) persons of scientific, technical, or literary attainments connected with or interested in the metal trades or with the application of non-ferrous metals and alloys.

Student Members shall be more than seventeen years of age, and shall not remain Student Members of the Association after they are twenty-five years of age, and shall be:—

either (a) Students of Metallurgy;

or (b) pupils or assistants of persons qualified for ordinary membership whether such persons are actually members of the Association or not.

Student Members shall not be eligible for election on the Council nor entitled to vote at the Meetings of the Association.

SECTION II.—ELECTION OF MEMBERS.

Rule 6.—Applications for membership shall be in writing in the form marked "A," and such application must be signed by the applicant and not less than three members of the Association.

Rule 7.—Such applications for membership as Ordinary Members or Student Members as are approved by the Council shall be inserted in voting lists. These voting lists will constitute the ballot papers, and will specify the name, occupation, address, and proposers of each candidate. They shall be forwarded to the members for return to the Secretary at a fixed date, and four-fifths of the votes recorded shall be necessary for the election of any person.

Every such election shall be subject to the payment by the applicant of his entrance fee and first annual subscription, and he shall not become a member of the Association nor be entered on the Register of Members until such sums are actually received from him. In the event of his failing to pay such sums within the time specified in the notification to him of his election, his election shall be void.

Rule 8.—Upon election under the preceding Article the Secretary shall forward to the applicant so elected notice thereof in writing in the form marked "B."

Rule 9.—In the case of non-election, no mention thereof shall be made in the minutes.

SECTION VI.—SUBSCRIPTIONS.

Rule 28.—The subscription of each Ordinary Member shall be two guineas per annum, and of each Student Member one guinea per annum. Ordinary Members shall pay an entrance fee of two guineas each, and Students an entrance fee of one guinea each.

Rule 29.—Subscriptions shall be payable in advance on July 1st in each year, save in the case of Ordinary Members and Student Members elected under Clauses 6 and 7 hereof, whose entrance fee and annual subscription shall become payable in accordance with the notification to them of their election. Every subscription shall cover the period down to the 30th of June next following, and no longer.

Rule 30.—Subject to the provisions of Clause 7 hereof, any member whose subscription shall be six months in arrear, shall forfeit temporarily all the privileges of the Association. Due notice on the form following marked "C" shall be given to such member, and if such subscription remains unpaid upon the date specified for payment in this notice, the Council may remove such member from the Register of Members of the Association, and thereupon any member whose name is so removed shall cease to be a member thereof, but shall nevertheless remain liable to the Association for such arrears.

May 15/16.

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